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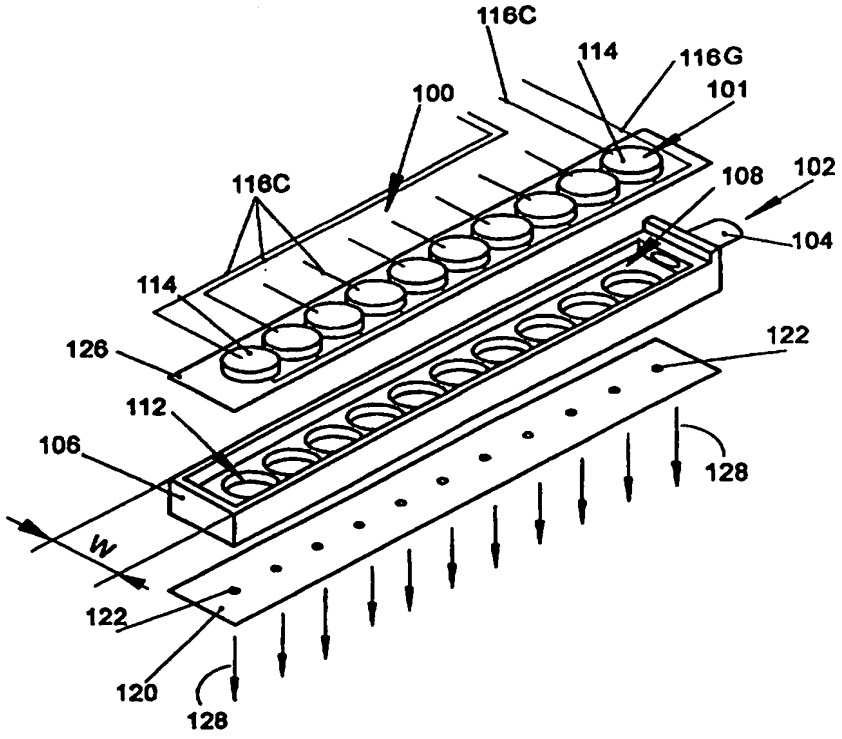
(54) Title: MULTICHANNEL MICRODOSING APPARATUS

(57) Abstract

A pumping apparatus has a body portion with a chamber and channels for receiving fluid that has entered the chamber through an opening in the body portion. The chamber is covered by a membrane and the channels terminate in orifices, through which fluid exits the pump. Electrosensitive members, movable in response to electric signals, are positioned on portions of the membrane corresponding to the respective channels, forming micropumps with the respective channels, within the pump body and the respective orifices. A control mechanism controls pumping of this apparatus by sending electrical signals to the electrosensitive members, that force fluid through the respective channels and out the respective orifice for delivery to the desired site. The control mechanism permits movement of at least one of the electrosensitive members independent of the other electrosensitive members, as well as concurrent and simultaneous movement of the electrosensitive members, depending upon the pumping mode desired.



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MULTICHANNEL MICRODOSING APPARATUS

FIELD OF THE INVENTION

The present invention relates to microdosing pumps and apparatus employing these pumps. In particular, the present invention is directed to pumps, formed of micropumps, that move highly precise amounts of fluid from one location to another. The pumps include multiple channels through which fluid is pumped by movement of an electrosensitive member. These microdosing pumps can be used alone, or as parts of other apparatus, including, for example, microdosators, infusion pumps, intravenous administration assemblies and inhalators.

BACKGROUND OF THE INVENTION

Microdosing involves providing very small precise amounts of fluid, typically on the order of microliters or less, from a reservoir or other fluid source. Typically, microdosing is used in laboratories where chemical, biological and medical research is being performed, as well as with the administration of drugs and other similar therapeutic agents. In these microdosing applications, very small precise amounts of a given fluid solution are typically introduced into biological tissue or mixed to prepare a chemical solution. The typical volume of fluid used in microdosage is between 0.5 microliters and 2500 microliters. Some microdosage applications, like infusion, require a repetitive supply of small fluid quantities. For example, microdosage associated with infusion into the body is performed at a rate of approximately 100 ml/hour to 1000 ml/hour, while microdosage from implantable pumps is on the order of approximately 1 microliter/hour to 100 microliters/hour.

Some contemporary microdosing equipment is mechanical, and operates by dispensing preset amounts of liquid from a reservoir. A pipette, of either single channel or multi-channel (serial) construction is an example of this contemporary equipment, commonly used in research laboratories. With this serial construction, each of the multiple channels is equivalent in volume and controlled by a single driver, in order to provide the same fluid volume from each channel. The fluid volumes drawn from these single and serial pipettes are typically accurate, within a few microliters, but not accurate enough for applications involving high precision, such as drug and chemical mixing.

Another contemporary microdosing device is shown in Figure 1A. This device includes a grippable body 2, that houses a piston moving mechanism (not shown), and an ejector camera 4, that has a metered volume. The ejector camera 4 attaches to a removable tip 6. The specific volume of the requisite microdose is by a manually adjusted dial mechanism 8. Again, this device is highly accurate, within a few microliters, but not accurate enough for applications involving high precision, such as drug and chemical mixing.

Microdosing is also used with infusion assemblies. These infusion assemblies are widely used in medicine for the delivery of medication, fluids and/or nutritional solutions into the patient's body. A typical infusion administration apparatus, shown in Figure 1B, includes a fluid bag/bottle 10 filled with medication, to which tubing 12 connects. This tubing 12 includes a needle 13 at its end, through which the fluid and/or nutritional solutions in the bag/bottle 10 enter the patient's body. Pumping of the fluid is performed by an electrically controlled peristaltic pump 14, into which the tubing 12 is threaded. Rhythmic occlusion of the tubing 12 by the pump 14 produces positive pressure and moves the fluid and/or solutions in the desired direction. The entire apparatus is mounted on a pole 16 or other elevating structure.

This conventional infusion apparatus exhibits several drawbacks, the most significant being accuracy and precision of the amount of fluid dispensed. Other

drawbacks associated with this apparatus includes the high cost. the requirement for trained skilled operators, and the requirement of periodic calibration, typically off-site, and their difficulty in supporting slow release infusion, required for administration of drugs such as insulin. Moreover, this apparatus is not designed for ambulatory use, as it occupies a large amount of space, thus, not allowing for substantial patient mobility. For proper and uninterrupted infusion, the treatment bag 10 must be static and elevated on the pole 16 at a point above the treatment site, in order to take advantage of gravity as well as the pumping action. Finally, when the pump is operated by a remote computer from a central nursing station, several indirect sensors be incorporated into the pump, making the administration assembly bulkier and more difficult to move.

Additionally, the tubing may also be the source of problems. For example, the tubing may clog when proteins, chemotherapy solutions and/or cardiac medicines are introduced into the body.

Attempts have been made to overcome these drawbacks associated with conventional devices. One attempt is shown in Figure 2, where a fluid solution in a bag 24 flows by gravity to a pump 28, through tubing 32. Additional tubing 36 connects the pump 28 to a needle 40 or cannula (not shown).

The pump 28 of this infusion apparatus is disclosed in U.S. Patent No. 5,205,819 (Ross et al.). The pump 28 has a body defining a chamber 44 of variable volume with one-directional inlet and outlet valves, and includes with a flexible wall 48 therein. This flexible wall 48 is deflected by a piezoelectric actuator 52 attached to it. The volume of liquid displaced from the chamber 44 in a single pumping action is a function of the amplitude of deflection developed by the membrane 48, as a result of the force applied by the piezoelectric actuator 52. The amount of liquid expelled may be metered by varying the amplitude and frequency of the piezoelectric actuator 52. The pump body is disposable and is connected to the housing by a releasable connector, which biases the wall 48 with a transducer into operative engagement. The transducer is provided with

sense electrodes to measure the amplitude of wall 48 deflection, which is used to trigger alarms, indicating the presence of bubbles in the chamber or of occlusions.

This system also has its drawbacks. It is sensitive to position, as it requires a suspension pole, to keep the fluid filled bag 24 above the level of the patient. This suspension pole also inhibits the mobility of the patient. Although disposable, the pump 28 requires an on-the-spot tubing connection, and thus the assistance of qualified personnel. The pumping ability is related to the presence of fluid at the entrance to the chamber 44, thus the fluid bag must always be elevated above the patient.

Other piezoelectric pumps are also known in the art. For example, peristaltic pumps employing piezoelectric materials are known. Reference SU 1776346 A3 discloses a peristaltic piezoelectric pump, where piezoelectric rollers rhythmically occlude the tubing, forcing liquid from the tube. U.S. Patent No. 4,115,036 (Paterson) discloses a peristaltic pump that comprises two concentric cylinders, at least one of which includes a plurality of piezoelectric elements which are successively electrically energized. This selective energizing produces moving seals, that move in a wavelike manner, in the region between the cylinders. The liquid is thus pumped in a wavelike manner.

U.S. Patent No. 4,944,659 (Labbe, et al.) discloses a dispensing device for use in an implantable drug delivery system for ambulatory patients. The device includes a pump housed in a pump chamber in a drug reservoir and a piezoelectric disc element bonded to a diaphragm member forming one wall of the pump chamber. The piezoelectric disc member is controlled by circuitry that cyclically applies voltage thereto, for inducing pumping movement in the diaphragm member, in order to pump medication from the reservoir to a catheter, for delivery to the body.

U.S. Patent No. 4,938,742 (Smits) discloses an apparatus of a series of silicon micropumps with piezoelectric material valves within each of the series of valve chambers. This apparatus can be used to pump liquids or gases at very low rates. However, this apparatus exhibits a major drawback, in that only one of the micropumps, of this series of micropumps, pumps at a time, as the micropump(s) neighboring the pumping micropump are used as one-way valves.

SUMMARY OF THE INVENTION

The present invention overcomes the drawbacks of the prior art by providing a pumping apparatus that includes multiple micropumps therein, for pumping precise amounts of fluids from a fluid source to the requisite delivery site. Each of the micropumps is individually operable by a control mechanism. This provides the present invention with high reliability and redundancy, as one or more of the micropumps are able to operate independent of each other, with concurrent operations of different micropumps in different pumping modes, and if desired, all of the micropumps can operate simultaneously. In case one or more of the micropumps fail, the load on the other micropumps may be easily changed, and/or additional micropumps may be added to the pumping apparatus to compensate for the failed micropump(s). Furthermore, the apparatus of the present invention can be scaled, enabling the apparatus to be designed over ranges, such that, for example, these pumps may be designed for ambulatory and implantable uses.

A pumping apparatus of the present invention includes a body portion having a chamber, with an opening in the body portion through which fluid flows into the chamber. A plurality of channels are in fluid communication with the chamber within the body portion. The chamber is covered by a membrane. Electrosensitive members, movable in response to electric signals, are positioned on portions of the membrane corresponding to the respective channels, forming

micropumps within the pump body. A control mechanism controls pumping of this apparatus by sending electrical signals to the electrosensitive members, that force fluid through the respective channels and out an orifice for delivery to the desired site. The control mechanism permits movement of at least one of the electrosensitive members independent of the other electrosensitive members, as well as concurrent and simultaneous movement of the electrosensitive members, depending upon the pumping mode desired.

Another pumping apparatus of the present invention includes a chamber that receives fluid, the chamber in communication with channels, for receiving the fluid from the chamber. The channels are formed intermediate adjacent rods of electrosensitive material. For example, the rods may be arranged linearly, adjacent in a chamber, or circularly, around a cylindrical chamber. A control mechanism controls pumping of this apparatus by sending electrical signals to the electrosensitive rods, causing a "squeezing action" by the rods. Additional chambers may be formed in the pumping apparatus, with porous material placed between rods, so as to subdivide the channels. The control mechanism permits movement of at least two adjacent electrosensitive rods independent of the other electrosensitive rods, as well as simultaneous movement of the electrosensitive rods, depending upon the pumping mode desired.

These pumping apparatus may be incorporated into devices for regulating fluid flow therethrough, thus providing the desired microdosing. For example, these pumping apparatuses may be placed into devices such as grippable body members along lines (tubing) of fluid administration apparatus, and fluid bags, such as those in intravenous administration apparatus, and the like, for providing the requisite microdosing. In these devices, the pumping apparatus are placed along a fluid pathway, intermediate a fluid supply source and a fluid outlet. In the fluid bag, the incorporation of the pumping apparatus of the present invention therein is such that connections to tubing prior to use and/or complicated control operations are not required, and thus, the fluid bags are disposable following use. Additionally, the pumping apparatus of the present invention may be placed

into a housing, the housing having structure for accommodating the passage of gases (e.g., air) between the top and bottom sides of the housing, so as to form an inhalator.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be described with reference to the accompanying drawings, wherein like reference numerals identify corresponding or like components.

In the drawings:

Figure 1A is a front view of a microdosator of the prior art;

Figure 1B is a front view of an intravenous infusion apparatus of the prior art;

Figure 2 is front view of an intravenous infusion apparatus employing a pump, in cross-section, of the prior art;

Figure 3A is a broken away front view of a microdosator employing the present invention;

Figures 3B and 3C are front views of intravenous infusion apparatuses employing the present invention;

Figure 4 is an exploded view of a first embodiment of the present invention;

Figure 5A is a chart of drop volume as a function of excitation frequency;

Figure 5B is a chart of drop volume as function of excitation pulse width;

Figure 6A is a broken away cross-sectional view of a microdosator employing the present invention;

Figure 6B is a cross-sectional view a second embodiment of the present invention;

Figure 7A is a cross-sectional view of a third embodiment of the present invention;

Figure 7B is a cross-sectional view of the embodiment of Figure 7A, taken along line A-A;

Figure 7C is a cross-sectional view of an alternate orifice plate used in the embodiment of Figures 7A and 7B above;

Figure 7D is a cross-sectional view of a fourth embodiment of the present invention;

Figure 7E is a broken away top view of the fourth embodiment of the present invention;

Figure 7F is a cross-sectional view of a fifth embodiment of the present invention;

Figure 7G is a broken away top view of the fifth embodiment of the present invention;

Figure 7H is an exploded view of a sixth embodiment of the present invention:

Figures 7I and 7J are cross-sectional views of a seventh embodiment of the present invention;

Figures 7K and 7L are cross-sectional views of an eighth embodiment of the present invention;

Figure 7M is a cross sectional view of a ninth embodiment of the present invention;

Figure 7N is a top view, including a broken away portion of a tenth embodiment of the present invention;

Figure 8A is a cross-sectional view of an eleventh embodiment of the present invention;

Figure 8B is a cross-sectional view of the embodiment of Figure 8A, taken along line A1-A1;

Figure 9A is a longitudinal cross-sectional view of a twelfth embodiment of the present invention;

Figure 9B is a transverse cross-sectional view of the embodiment of Figure 9A;

Figure 10A is a longitudinal cross-sectional view of a thirteenth embodiment of the present invention;

Figure 10B is a transverse cross-sectional view of the embodiment of Figure 10A;

Figure 10C is a transverse cross sectional view of a fourteenth embodiment of the present invention, and in particular, an alternate embodiment of the apparatus shown in Figures 10A and 10B;

Figure 11 is a broken away cross-sectional view of a microdosator employing the present invention;

Figure 12A is a cross-sectional view of a fifteenth embodiment of the present invention;

Figure 12B is a cross-sectional view of the embodiment of Figure 12A, taken along line B-B;

Figure 13 is a longitudinal cross-sectional view of a sixteenth embodiment of the present invention, and in particular, an alternate embodiment of the apparatus shown in Figures 12A and 12B;

Figure 14 is a broken away cross-sectional view of a microdosator employing the present invention;

Figure 15 is a cross-sectional view of a seventeenth embodiment of the present invention;

Figure 16 is a cross-sectional view of a fluid bag in an intravenous administration apparatus employing the present invention;

Figure 17A is a transverse cross-sectional view of a fluid bag employing the present invention;

Figure 17B is a cross-sectional view of the fluid bag of Figure 17A, taken along line A2-A2;

Figure 18A is a partial transverse cross-sectional view of an eighteenth embodiment of the present invention;

Figure 18B is a partial longitudinal cross-sectional view of the embodiment of Figure 18A;

Figure 19 is a partial cross-sectional view of a nineteenth embodiment of the present invention, and in particular, an alternate embodiment of the embodiment shown in Figures 18A and 18B;

Figure 20A is a partial cross-sectional view of a twentieth embodiment of the present invention;

Figure 20B is a side view of the embodiment of Figure 20A; and

Figure 21 is a cross-sectional view of a twenty first embodiment of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

Turning now to the drawing figures, Figure 3A details a microdosator 60 with a pump 62 of the present invention (detailed below and shown in Figures 4 through 15) incorporated into it. The pump 62 is actuated to make a preset and calibrated amount of pumping actions that result in a desired dose of the liquid. The fluid is released from the microdosator 60 through a replaceable tip 64.

Figure 3B shows an intravenous administration set having a fluid bag 66 with tubing 68 extending therefrom, and a pump 70 of the present invention (detailed below and shown in Figures 4 through 15) incorporated along the tubing 68. The pump 70 is actuated to pump the fluid/medication from the fluid bag 66 to the body of the patient (not shown). The pump 70 may be driven from a local or remote controller/computer 72.

Figure 3C shows a pump 76 of the present invention (detailed below and shown in Figures 4 through 15) incorporated into a fluid bag 80. The fluid bag 80 is incorporated into an intravenous administration apparatus. As discussed above, the pump 76 may be driven from a local or remote controller, such as a computer 84.

Figure 4 shows a pump 100 of the invention, of multiple micropumps 101 formed from multiple channels. While ten micropumps 101 are shown in this drawing figure, there may be more or less than this number of micropumps depending on the desired application. In this embodiment the fluid flows from the fluid source (not shown) in the direction indicated by arrow 102, through the

connective tubing 104, preferably attached to the body 106, but not part of the body 106. The fluid fills in the common input chamber 108 of the pump 100.

The multichannel pump body 106 is preferably made of easily sterilizable materials such as stainless steel, plastic or glass. The body 106 includes recesses (cutouts) 112 that form channels. The liquid from the common chamber 108 flows into the recesses (channels) 112. Opposite each of the recesses 112, an electrosensitive member 114 has been placed in contact with a portion of the membrane 126. The electrosensitive members 114 are preferably piezoelectric members preferably in the form of disc type ceramics, commercially available from Fuji Ceramics Co., Fujinomiya City, Japan, or Morgan Matroc, Inc. Bedford, OH 44146, USA.

Preferably, the electrosensitive member 114 is of a single disc. The pump 100 is operated by a driving signal which is sent from a computer (not shown), or from a local controller. The driving signal is fed to each of the electrosensitive members 114 by a set of contact wires 116G, that serve as a common ground wire, and conducting wires 116C, that conduct the actual drive signal, from a controller, such as a computer (not shown). The pump 100 and the controller are attached by a connector (not shown).

The recesses (channels) 112 are covered by an orifice plate 120, preferably in the form of a sheet, with at least one orifice 122, for each recess (channel) 112. Although one orifice 122 corresponding to each recess 112 is shown, additional orifices are permissible. The orifices 122 are preferably round, but can be other shapes such as circular, rectangular, square, polygonal, triangular, oval, etc. Each recess (channel) 112 and its respective electrosensitive member 114 and orifice 122 are preferably coaxial and define each individual micropump 101. When the electrosensitive member 114 is activated (by an electrical signal from the controller), the electrosensitive member 114 moves (in a pumping action) so as to expel fluid from the chamber 108,

through the respective recess (channel) 112 and through the respective orifice 122 in the direction(s) indicated by the arrows 128.

Although the orifice plate 120 is not necessary, it is preferred, for the orifice plate 120 (with the orifices 122 therein) serves as a metering device, allowing for fixed and repetitive amounts of liquid to be expelled at each actuation cycle of the electrosensitive members 114. This metering is achieved as the orifices 122 may all be of the same diameter (size). Additionally, it is permissible, that the orifices 122 need not all be of the same diameter (size). Rather, one or more of the orifices 122 may be of a different diameter than one or more of the remaining orifices 122, in order to finely regulate the desired throughput of the pump 100.

The orifice plate 120 may be of Teflon®, capton, polyimide, glass or stainless steel, with orifices preferably of a diameter (size) between approximately 20 microns to 400 microns. The orifices 122 may be created in the orifice plate 120 by processes including laser ablation or the methods described in Hayes, et al., "Overview of Small Holes", in Society of Manufacturing Engineers (SME) Technical Paper, Non-Traditional Machining Conference, Orlando Florida, October 30-November 2, 1989, incorporated by reference herein.

When the multichannel pump 100 is operative, the controller generates and sends an electrical signal(s) to one or a number of electrosensitive members 114, that are contacted with a portion of the membrane 126 (of materials such as stainless steel, glass, or the like), that is in turn attached to the body 106. The signal activates the respective electrosensitive members 114 that accordingly bends the portion of the membrane 126. During the contraction cycle of the electrosensitive members 114, the membrane 126 expels the fluid through the respective channels 112 and respective orifices 122, and during the expansion

cycle, it creates pressure that pulls fluid from the common input chamber 108, to which it is fed from the liquid source.

Should an increase in the throughput of the pump be desired, an additional number of electrosensitive members 114 may be operated. The controller is also such that any one or any number of the electrosensitive members 114 can be operated independently of any one or any number of the other electrosensitive members 114, at different frequencies, at different pulse widths, and for different time periods, in order to finely regulate the desired throughput through the pump 100. As the frequency increases, the amount of liquid ejected from the recess (channel) 112 in each cycle decreases, such that the overall throughput is higher. For example, the controller is such that every one of the electrosensitive members 114 can be operated independently of every other of one of the electrosensitive members 114. Also, the electrosensitive members 114 could be operated simultaneously at the same frequency, pulse width and time period. Preferably, the voltage required to operate the electrosensitive members 114 is approximately 10 volts to 100 volts. It is also preferred that the electrosensitive members 114 (i.e., the piezoelectric ceramic element(s)) be operated in a frequency range of 2 KHz to 30 KHz, leading to an amount of expelled fluid between approximately 20 picoliters and 1000 picoliters. Larger volumes of fluid can be ejected at lower operating frequencies and through larger orifice diameters.

The preferred dimensions of such a pump 100 are approximately 5 mm to 9 mm in the dimension indicated as "W". The diameter of the recesses (channels) 112 is approximately 4 mm to 8 mm. The depth of the recesses (channels) 112 is approximately 0.2 mm to 0.4 mm. The diameter (size) of the electrosensitive members 114 is preferably approximately 10% to 15% less than the diameter of the recesses. The distance between the neighboring recesses 112 and orifices 122, respectively, is defined by the diameter of the electrosensitive members 114 used. The length of the pump 100 is defined by the throughput range desired for the transfer of a particular liquid, e.g., a pump

with throughput varying from 0.3 milliliter/hour to 50 milliliter/hour may have 6 to 10 micropumps and would be approximately 32 mm long.

The micropumps 101 of the pump 100, depending on the force developed by the electrosensitive members 114, caused by frequency of excitation, width of the excitation pulse; the diameter of the orifice 122; and fluid viscosity, always ejects a fixed and constant amount of liquid. Figure 5A indicates the variation in the drop volume as a function of the excitation frequency, and Figure 5B indicates variations in the drop volume as a function of the excitation pulse width. In both cases (Figures 5A and 5B), the orifice diameter was 25 microns and the liquid tested was water.

A microdosator 130 incorporating the pump 100 (detailed above and shown in Figure 4) is shown in Figure 6A. The microdosator 130 includes a grippable body 132 having a reservoir 134 containing fluid therein. The fluid (that may be replaced or replenished by accessing the reservoir 134 through the removable cover 136) to be dispensed flows from the reservoir 134, in the direction indicated by the arrow 138, through the connecting tube 144 into the pump 100. Alternatively, the remote fluid sources are also permissible, and connected by an umbilical tube 142 to the microdosator 130. The fluid then flows into the common input chamber 108 (Figure 4) of the pump 100, whose operation is detailed above.

The microdosator 130 is operated by a driving signal which is sent from a computer located close to the microdosator 130, or from a built-in controller through a connecting cable (not shown) in the umbilical tube 142, or alternately, a built-in controller, eliminating the need for the connecting cable. The fluid expelled by each of the micropumps 101 is collected in the common output chamber 146, the walls of which are coated by a specific liquid repellent material, such as polyurethane, polypropylene, or the like. Fluid exits the microdosator 130 through a passage 147 in the removable tip 148 in the direction of the arrow 150.

In Figure 6B the pump 100 (detailed above and shown in Figure 4) is incorporated into a production line that produces accurate concentrations of fluid(s), including medication, drugs, perfumes or other chemical solutions. The pump 100 is held by a holder 156 over a conveyor line 158, which moves vessels 160 with the solution to be produced, in the direction perpendicular to the paper plane. The fluid to be dispensed flows from a fluid reservoir (not shown) or other fluid source in the direction indicated by the arrow 162 through a conduit 163 to input chamber 108 of the pump 100. Once in the pump 100, each of the micropumps 101 dispenses fluid into the appropriate vessel 160.

The pump 100, operated in accordance with that detailed above, may be actuated by a driving signal (or signals) that is sent through a connecting cable 164 from a remote computer or other similar controller. As detailed above for the pump 100 (Figure 4) by varying the rated frequencies, pulse widths, orifice size and/or duration of operation, different volumes of fluid may be dispensed. To adapt to different vessel sizes, the pump 100 may be produced with different distances between the individual micropumps 101 than those indicated above. The pump 100 may be designed such that the center-to-center distance between the micropumps 101 matches the distance between the vessels 160. Also, groups of micropumps may be centered around these points.

In Figures 7A and 7B, the pump 100 (as detailed above and shown in Figure 4) is incorporated into an infusion apparatus in a fluid transport line 165, where the fluid (i.e., medication) flows from the infusion bag (not shown) in the direction indicated by the arrow 170, the medication enters a tube 172 in the fluid transport line 165, the tube 172 carrying the fluid to the input chamber 108 of the multichannel pump 100. The pump 100 is operated (in accordance with that described in Figure 4 above) by a driving signal which is sent from a controller, such as a computer (not shown). The driving signal is fed to each of the electrosensitive members 114 along contact wires 174. There is also a ground

wire 176. The connection between the pump 100 and the controller is performed with a connector 178.

As detailed for the pump 100 in Figure 4 above, the driving signal from the controller activates the electrosensitive members 114 that bend the membrane 126 accordingly. During the contraction cycle of the electrosensitive members 114, the portions of the membrane 126 moved by the activated electrosensitive members 114, expels the fluid (i.e., medication) through the respective orifice 122 (in the orifice plate 120), and during the expansion cycle, it creates pressure that pulls it from the common chamber 108, previously fed fluid (i.e., medication) from the infusion bag (not shown). The fluid, expelled by successive pumping actions of the respective electrosensitive members 114, creates pressure in the common output chamber 180, which is higher than the back pressure generated by blood pressure in the blood vessel, and in particular, a vein. This pressure creates a flow of fluid (i.e., medication) in the direction indicated by arrow 182. One-way valves 184 and 186, serve to prevent a back flow of the fluid (i.e., medication) into the fluid bag during the pumping cycle and from the lower part of the administration set during the suction cycle. Although the active pumping action may be performed by a limited number of micropumps 101, all of the remaining micropumps 101 should be operated at a level which creates a certain amount of pressure in the common chamber to prevent backflow of fluid (i.e., medication) into the neighboring recesses (channels) 112 (Figure 4). When it is necessary to increase the throughput of the pump, an additional number of electrosensitive members 114 may be operated. For intravenous infusion, the electrosensitive members 114 are operated at voltages of preferably approximately between 20 volts and 50 volts. Alternatively, the electrosensitive members 114 may be operated at a higher than rated frequency, as well as the orifice plate 120 may have a set of orifices 122 of different sizes (as discussed above).

Since the fluid in the pump 100 is expelled against the pressure in the blood vessels, specifically a vein, the orifice plate 120 (Figure 4) should be of a thickness so as not to adversely affect the pumping action. An alternate orifice

plate 120' for the pump 100 in the fluid transport line 165 is shown in Figure 7C. This alternate orifice plate 120' includes conical orifices 122' that taper downward (in the direction of fluid expulsion). The arrows 128a indicate the direction in which the fluid (i.e., medication) is expelled through this orifice plate 120'.

Figures 7D-7M show embodiments of micropumps, that are similar in construction and operation to the micropumps 101 described and shown in Figure 4 above. The micropumps shown in these figures can be combined to form a pump structure, in a manner similar to the pump 100 of Figure 4. The components of these micropumps 101, such as the body members, electrosensitive members, membranes and orifice plates (as sheets 120 or plates 120') having orifices, are of similar materials and construction to their counterpart components in the micropump 101 of Figure 4. Additionally, the electrosensitive members of these micropumps may be controlled by control mechanisms similar to those detailed for the micropumps 101 of Figure 4, for pumping in the modes detailed above for the pump 100 of Figure 4.

A valveless micropump 187 in accordance with the present invention, is shown in Figures 7D and 7E. In this micropump 187, both the incoming and outgoing medication flow, indicated by arrows respectively labeled "In" and "Out", pass through a common orifice plate 188, in which the orifices 189a and 189b are shaped like opposing, venturi-like cross sections. This arrangement facilitates the flow of the incoming fluid into the chamber 190 and reduces the back flow of the fluid from the chamber 190 during the pumping cycle. Multiple micropumps may be connected to create a complete, multi-channel, infusion pump 200 (Figure 7E). The fluid may be supplied from an infusion bag (not shown) to each of the micropumps 187 through individual supply channels or through a manifolds 192. The first manifold 192 may be common to all of the micropumps or separate for each micropump. The fluid pumped by each of the micropumps 187, when the respective electrosensitive members 194 on the membrane 196 are activated, is delivered through a second manifold 198 to the patient. This

pump 200 may be incorporated into an intravenous administration apparatus or in a fluid bag (as discussed above).

A micropump 211, similar in construction and operation to the micropump 187 shown in Figures 7D and 7E (detailed above), is shown in Figures 7F and 7G. This micropump 187 has two one-way valves 202 and 204, that serve to prevent a back flow of fluid (i.e., medication) into the fluid bag (not shown) during the pumping cycle, and from the lower part of the administration set during the suction cycle. These one-way valves 202, 204 are conical recesses 202a, 204a, with fluid flow inhibiting members 206, preferably glass or plastic balls placed into these conical recesses 202a, 204a. These fluid flow inhibiting members 206 are retained within these conical recesses 202, 204 by a thin, elastic, nylon net 209 attached to both sides of the plate 210. The properties of the net 209 are such that its elasticity allows the balls to move toward the respective nets 209 for proper fluid transport through the respective micropumps 211.

In Figure 7H, there is shown another embodiment of a single micropump 212 that may be a module of a multi-channel pump with individual checkvalves attached to each micropump. In this embodiment check valves 213, 214, are in thin membranes 216a, 216b. These check valves 213, 214 have thicknesses approximately 25 microns to 37 microns, and are preferably formed by electrochemical etching or laser cutting, and attached to both sides of the orifice plate 218. The membranes 216a, 216b are attached in such a way that the check valves 213 and 214 coincide with their respective through holes 220 and 222. The lengths of the check valves 213 and 214 are preferably larger than those of their respective through holes 220 and 222. A "sandwich" of the membranes 216a, 216b, with the orifice plate 218 therebetween, is inserted into the body 224 of the micropump 212, with a compression chamber 225 formed intermediate the membrane 228 and check valve 213. Portions of the membrane 228 are covered by an electrosensitive member 226, preferably of an element of a piezoelectric ceramic (detailed above). During the suction cycle, the check valve 213 opens and allows the flow of medication to fill the compression chamber 225, while the other

check valve 214 is closed and rests on the orifice plate 218, preventing any return flow of the fluid into the compression chamber 225. The opposite sequence takes place when the fluid is expelled from the compression chamber 225. Fluid direction, into and out of the micropump 212, is indicated by the arrows, respectively labeled "In" and "Out".

In Figures 7I and 7J, there is shown a micropump 234 similar to that of Figures 7D and 7E. The micropump 234 is of a construction that permits a response time of the check valves that is asynchronous from the pumping action of the electrosensitive members. The micropump 234 of this embodiment achieves this asynchronous action, as one of the walls 230 of an outlet subchannel 232 of the micropump 234 is made of a flexible material for movement between an untensioned position (shown in solid lines), and a tensioned position (shown in broken lines) in Figure 7I. A check valve 236, moveable between a closed position (shown in solid lines), and an open position (shown in broken lines) in Figure 7I, is mounted on another wall. When the electrosensitive member 238 is activated, fluid is pumped from the chamber 237 into the subchannel 232, through an orifice 233 of a venturi-like cross section (detailed above). As the pressure and the amount of fluid in the outlet subchannel 232 increases, the flexible wall 230 (detailed above) deflects to its maximal tensioned position, as shown in solid lines in Figure 7J. When the pressure exceeds certain advanced preset pressure, such as the back pressure of the blood in the blood vessel, e.g., a vein, the check valve 236 opens and moves to the open position (shown in solid lines in Figure 7J). The flexible wall 230 deflects back to its initial position (shown in solid lines in Figure 7I), pushing the excessive volume of liquid out of the outlet subchannel 232 through a port 240 (in the direction of the arrow labeled "Out"). As the pressure in the outlet subchannel 232 decreases, the check valve 236 returns to its closed position and the cycle is repeated. Since the flexible wall output chamber 232 serves as an accumulator of both energy and fluid, the pumping action of the electrosensitive member 238 becomes independent from the action of the check valve 236, that

may be significantly slower. It is preferred that, the volume of the outlet subchannel 232 should be significantly larger than the volume of the liquid expelled by a single pumping action by anywhere between 10 to 30 times.

The micropump 234, also includes an inlet port 243, for receiving fluid from a supply source (in the direction of the arrow labeled "In"), an inlet subchannel 244 and an orifice 245 of a venturi-like cross section, through which fluid flows to reach the chamber 237 for subsequent pumping by the electrosensitive member 238. Although Figs 7I and 7J show a single micropump 234, it may be one of many similar micropumps that are joined together to form a complete, multichannel pump, similar to the pump 100 shown in Figure 4 (above).

Another valveless embodiment of a micropump 246 that supports asynchronous operation of the check valve and the pumping action is shown in Figures 7K and 7L. This micropump 246 includes components similar to those for the micropump 234 described and shown in Figures 7I and 7J (above). This embodiment includes an inlet channel 247, with an inlet port 247a, and an outlet channel 248 with an orifice 249 therebetween. The orifice 249 is, preferably of a venturi-like shape (as described above). The outlet channel 248 includes flexible walls, allowing movement between a relaxed position (Figure 7K) and an expanded position (Figure 7L). This channel 248 is preferably constructed from a piece of flexible, polymeric or rubber tubing, that connects at the orifice 249 and terminates in a check valve 250, that moves between a closed position (solid lines in Figure 7K) and an open position (broken lines in Figure 7K and shown in Figure 7L). When this micropump 246 is in operation, the electrosensitive member 251, resting on a portion of the membrane 252, draws fluid in the inlet channel 247, through the orifice 249 into the outlet channel 248. When the pressure in the outlet channel 248 causes expansion to the expanded position, and this pressure exceeds the preset pressure on the check valve 250, the check valve 250 opens (Figure 7L) and a fluid volume exits the outlet channel 248. Fluid exit continues until the pressures on both sides of the check valve 250

equalizes. The amount of expansion of the outlet channel 248, as a function of pressure, depends on the dimensions of the outlet channel 248, (inner/outer diameter) and the properties of the material from which it is formed.

Figure 7M details a valveless pump 253 formed by cascading micropumps 254a, 245b, 254c. Figure 7N shows this pump 253 as incorporated into a larger pump 255, also formed of a cascaded array of micropumps 254a', 254b' and 254c', of similar construction to micropumps 254a, 254b and 254c, and discussed below, except that the micropumps 254a' have a common fluid supply chamber. Each of the micropumps 254a-254c includes channels 256a-256c, covered by a membrane 257, with an electrosensitive member 258, resting on at least a portion of the membrane 257. All of the channels 256a-256c include orifices 259a-259d, that are designed in accordance with those detailed and shown in Figures 7D-7L above. Orifice 259a serves as an inlet port (for fluid flowing in the direction of the arrow labeled "In"), orifices 259b and 259c, serve to allow fluid transport between channels 256a-256c, while orifice 259d, serves as an outlet port (from which fluid flows in the direction of an arrow labeled "Out"), and are preferably arranged in a straight line. If the electrosensitive members 258 are operated at the same time (synchronously), the total pressure generated by the cascaded array of micropumps 254a, 254b, 254c, is the sum of the pressures generated by each individual micropump 254a-254c. By this arrangement, the pump 253 develops relatively high pressure, that is needed to overcome the high resistance to flow in certain applications (i.e., back pressure in blood vessels, preferably mammalian blood vessels, such as veins). This same construction can be used for cascaded arrangements of two or more micropumps.

Due to the high pressure of the pump 253, its outlet orifice 259d can be connected to a fluid administration apparatus, through a flow restricting/regulating element (not shown), with a high resistance to flow. This arrangement will result in a relatively constant flow, that is unaffected by changes

in the administration apparatus or the back pressure in the blood vessels. e.g., veins.

Turning also to Figure 7N, the pump 253 of Figure 7M is incorporated into the pump 255, forming two arrays 260a, 260b of micropumps, 254a, 254a', 254b, 254b', 254c, 254c'. The first array 260a and the second array 260b are shown in broken lines for explanation purposes only. The pump 255 is formed of a body member 262 (of the materials disclosed above for the body member 106 of Figure 4), of single or multiple pieces.

The first array 260a includes a first series of micropumps, 254a' whose construction is similar to that shown in Figure 4 and detailed above. Any or all of the channels (not shown) of these micropumps 254a', have a common fluid inlet port (not shown). Each micropump 254a' of this first series forms a second series of cascaded micropumps 254a', 254b', 254c', as this micropump 254a' is preferably connected with a second micropump 254b' (through an orifice 259b', similar to the orifice 259b described above), that is in turn connected with a third micropump 254c' (through an orifice similar to the orifice 259c). These micropumps, 254a', 254b', 254c' are in a linear arrangement and are constructed in accordance with Figure 7M, as detailed above. It is preferred that each second series be independent of each other second series, with the only common fluid flow occurring in the fist series of micropumps 254a' in the first array 260a. Each of the second series of micropumps 254a', 254b', 254c' may terminate through orifices similar to orifice 259d in Figure 7M, in one or more reception containers (not shown). While this linear arrangement is preferred for the second series of micropumps, other cascading (non-linear) arrangements are also permissible.

One or more independent series of micropumps 254a, 254b, 254c, like that shown in Figure 7M, may also be incorporated into the pump 255, forming the second array 260b. This array 260b forms an additional second series that is preferably independent from all of the other second series, but its outlet orifice 259d may connect to a reception container as described above (not shown),

where at least one outlet of any of the second series of micropumps empties into as well. Preferably this arrangement is suitable when precise mixing of fluid solutions is desired. Certain locations for fluid flow into and out of this pump 255 are indicated by arrows labeled "In" and "Out".

Figures 8A and 8B show another embodiment of a multichannel pump 280 used in a fluid transport line 282, in an apparatus, similar in construction to the line 165 and apparatus detailed and shown in Figures 7A and 7B above. This fluid transport line 282 also employs the pump 100 (Figure 4) with slight modifications to the line 282, the modifications noted below. Fluid (i.e., medication) flows through this line 282 in the directions of the arrows 283a, 283b. This fluid transport line 282 employs porous material elements 284, 286 in the pump 280 at the fluid entry and intermediate each of the micropumps in the common chamber, and at least one porous material element 288 in the common output chamber within the fluid transport line 282. The above discussed porous material may be Pore®, porous plastic sheet materials, commercially available from Porex Technologies Corp., Fairburn, GA 30213, or porous sintered glass material commercially available from Robu®, Glasfilter-Gerate Gmbh., D-57644 Hattert, Germany, or porous sintered stainless steel of proper micron grade, commercially available from Mott Metallurgical Corp., Connecticut, U.S.A., cut into the shapes necessary for placement in the fluid transport line 282.

These porous material elements 244, 286, 288 are in constant hydraulic communication with the fluid in the fluid bag (not shown) attached to the fluid transport line 282. This porous material serves to draw fluid (i.e., medication) out of the fluid bag, by capillary action or wicking. This drawing of fluid is not dependent on gravity, and occurs regardless of the position of the bag, above or below the patient level, provided that the porous material elements 244, 286, 288 are in hydraulic communication with the fluid in the fluid bag. As a result, the common chamber of the pump 280 fills with liquid. The fill rate of the common chamber is a function of the grade of the porous material used. The porous material also acts as a filter for trapping foreign particles. Following the priming

of the chamber of the pump 280 and the porous material 284, 286 filling with fluid, all air bubbles that may be present or generated in the fluid and may proceed to the body of the patient will be trapped in the porous material 284, 286.

Another embodiment of a multi-channel, piezoelectric infusion pump 300 (preferably disposable), as part of a fluid delivery apparatus 301, preferably connected to a fluid bag (not shown), preferably housed in a plastic envelope 301a, is shown in Figures 9A and 9B. This embodiment of the infusion pump 300 utilizes piezoelectric effect. The pump 300 may be constructed from a monolithic piezoelectric ceramic material 312, such as Lead Zirconium Titanate (PZT), into which channels 308 are cut and the material is poled (polarized) in a direction indicated by an arrow "a". The typical dimensions of such channels would preferably be about 0.2 mm to 0.4 mm in width, 0.8 mm to 1.0 mm in height and about 15 mm to 40 mm in length. The walls (ribs) 316 surrounding the channels 308, define micropumps 317. The walls 316 are similar in size, and serve as actuators for pumping upon receiving an electrical signal(s) from the connector 324 and controller 328. i.e., a computer, this controller similar to that described above. The respective sides of the walls 316b, 316c, are coated with metal (metalized), preferably along their entirety, in accordance with the direction in which the walls 316 are poled (polarized). This metal coating is preferably coated with a passivation layer, to avoid hydrolysis of the fluid being transported through the apparatus 301 and electrical short circuits.

The metal coating of the walls 316 serves as an electrical contact through which a drive signal(s) is provided to activate the wall 316. When an electrical signal(s) is applied to the walls 316, the walls 316 move transversely (by bending) in the direction of the field, and increase liquid pressure in the respective channels 308. This movement creates an under pressure in a neighboring channel 308, which, in addition to capillary forces present in the channels 308, facilitates the flow of liquid from the fluid bag (not shown). The

medication pulled out of a fluid bag by these forces fills a common chamber 332 in the pump 300, prior to the fluid being distributed into each of the channels 308.

The side of the channels 308 opposite that of the chamber 332, is closed by an orifice plate 336, in which small orifices 340, in accordance with those discussed above, are produced. The orifice plate 336 is similar in construction and materials to the orifice plate 120 detailed in Figure 4 above, but designed for the specific shape of the pump 300. Alternatively, the orifice plate 336 may have check valve like arrangements, as described above in Figures 7D-7J. Similar to that detailed above, the orifice plate 336 may be made of capton, in which the orifices 340 are produced by laser ablation. Alternatively, the orifice plate 336 may be made of Teflon, polyimide, glass or stainless steel. The fluid (i.e., medication) is ejected from each of the channels 308 through the orifices 340 into a common chamber 344, and is conducted to the needle/patient (not shown) through the tube 348. A one-way valve 352 prevents the medication from flowing back into the pump 300 (as fluid flow through the pump 300 is in the direction of the arrows 355a, 355b). A porous material filter 356 (of any of the porous materials described above) may be used to trap the air bubbles that may be present in the fluid (e.g., medication).

In operation, the electrodes at the walls 316b may be connected to a common ground and the electrodes at the walls 316c may be connected to a signal line. Both electrodes at the walls 316b, 316c connect to lines (not shown) that are in turn connected to the connector 324, that connects with the computer or controller 328 that provides the drive signal to the pump 300.

In the dimension "L", it is preferred that the pump 300 constructed according to this embodiment be approximately 20 mm to 25 mm, and approximately 3 mm to 4 mm in the dimension "h." Depending on the desired throughput, the dimension "W" will be about 15 mm to 25 mm. The throughput of the pump 300 may be changed by varying the operating frequency of the walls 316, that preferably operate in a frequency range of 4 KHz to 50 KHz, a number

of these walls operating simultaneously, and developing the force required to eject the fluid against the back pressure of the blood in a blood vessel (e.g., a vein).

Figures 10A-10C are cross-sectional views of a multichannel, infusion pump 365 (preferably disposable), similar in construction and operation to the pump 300 detailed and shown in Figures 9A and 9B above. Fluid flows through the pump 365 in the direction of the arrows 365a, 365b. The pump may also include a one-way valve 365c. The pump 365 is incorporated into an administration apparatus 366 and is preferably housed in a plastic envelope 366a. In this particular embodiment, the pump 366 consists of two or more rows of micropumps 367, formed by rods 370, 372, forming channels 373 therebetween, separated by a plate 374 of porous material (as described above). The pump 365 may be manufactured of a piezoelectric material similar to those described above (Figures 9A and 9B) and by making a set of substantially parallel grooves in oppositely disposed plates 376, 378. The rods 370, 372 are inserted in the grooves and maintained with glue or other similar adhesive. The rods 370, 372 are poled (polarized) prior to assembly and are positioned intermediate the plates 376, 378, such that upon assembly, the rods 370, 372 are poled (polarized) in the direction of the arrow "a". Similar to that described above, the sidewalls of the rods 370b, 370c, 372b, 372c are metalized (in accordance with the direction of the poling of the rods 370, 372). This metalizing provides the contacts necessary for the rods 370, 372 to receive electrical signals for movement (pumping). Electrical signals are carried to the rods 370, 372 through a connector 324 (similar to that described in Figures 9A and 9B above), designed for attachment to a controller (i.e., an electrical signal generator) (not shown), similar to those detailed above. Sidewall plates 380, serve to maintain the rigidity of the construction of the pump 365. The back plate 382 is then attached to the assembly and creates a common input chamber 384 for the pump 365. The metalized sidewalls of the rods 370b, 370c, 372b, 372c are coated with a passivation coating to prevent hydrolysis of the fluid (e.g.,

medication) as well as short circuiting of the electrical system that sends electrical signals to the rods 370, 372. The pump 365 is covered by an orifice plate 386 (as described above for Figures 4, 9A and 9B) in which there are orifices 388, at least one corresponding to each channel 373.

Figure 10C is similar to Figure 10B, except the pump 365 rods 370', 372' are poled (polarized) in a different direction (perpendicular) to the rods 370, 372 in Figure 10B. This perpendicular direction is indicated by the arrow a'. Electrical contacts are deposited on the surfaces 370d, 370e, 372d and 372e, eliminating any contacts between current conducting surfaces and the fluid. The pump 365 and apparatus 366 into which it is incorporated (Figures 10A-10C), operates similar to the pump 300 and apparatus 301, disclosed in Figures 9A and 9B.

Figure 11 shows a microdosing device 391 employing the pump 300 (and control mechanism) of Figures 9A and 9B. Alternately, this device 391 could employ the pump 366 (and control mechanism) of Figures 10A-10C. The body 392 of this device 391 is similar to that shown in Figure 6A, except that the removable tip 396 of the device 391, may include an orifice plate 398 (as described above), having at least one orifice corresponding to each of the channels of the respective micropumps. By changing the orifice plate 398, to a plate with different sized orifices (as described for the orifice plate 120 of Figure 4 above), thus allowing for emission of differently sized drops from the device 391.

Another embodiment of a multichannel piezoelectric pump 400, operating similar to the pumps 300, 365 of Figures 9A and 9B, and 10A-10C, respectively, is shown in Figures 12A and 12B. The body 400a of the pump 400 is preferably round (cylindrical), and forms part of a fluid administration apparatus 401. The rods 402 are formed of electrosensitive materials (preferably the piezoelectric ceramic materials as discussed above), poled (polarized) in the radial direction as indicated by the arrows. The rods 402 may be tapered, as well as trapezoidal or rectangular in shape. The rods form micropumps 403 therebetween. The

preferred dimensions for the rods 402 are between 0.3 mm and 0.5 mm in width, about 0.8 mm to 1.2 mm in height and about 30 mm to 40 mm in length.

The pump 400 may be assembled by attaching the rods 402 to the inner cylinder 406 and outer cylinder 408. To facilitate this process, precut grooves may be made on the inner cylinder 406 or on both the inner and outer cylinders 408. The outer cylinder 408 fits within a cut-out section 409 of the wall of the fluid administration apparatus 401. The rod sidewalls 402a and 402b are metallized (and coated with a passivation coating as described above) and provide the contacts through which the driving signal from a controller 410 (similar to the pump controllers described above) by a cable 412 and connector 414, that moves the rods 402 for pumping. One of the metalized sidewalls 402a, 402b, may be connected to a common ground (not shown), while the other of the metalized sidewalls 402a, 402b is connected to a signal, preferably electric signal, generator of the controller. Alternately, similar to the other above embodiments, the rods 402 may be poled in a perpendicular direction to the one shown, and accordingly, the surfaces 402c and 402d will be metalized (and coated with a passivating material, as described above) accordingly, to serve as electrical contacts.

The fluid from a fluid supply (i.e., a reservoir) flows in the direction indicated by arrow 416. It fills in the common input chamber 418. To prevent uncontrolled penetration of the fluid downstream, the bottom of the common input chamber 418 is closed by a plug 420, that prevents undesired and uncontrolled leakage of the fluid.

The inner cylinder 406 is preferably made of a porous material (described above), that draws the fluid from the common input chamber 418 into each of the channels 422. Each channel 422 acts as an individual micropump. The outlet portion of the channels 422 is closed by an orifice plate 424 in which orifices 426 facing each of the channels 422 are made. The orifice plate 424 is similar in construction to the orifice plate 120 (detailed and shown above in Figure 4), but

modified for the particular shape of the pump 400. The orifice plate 424 may be combined, if desired, with the plug 420. Alternately, the orifice plate 424 may also be constructed to have check valve like arrangements described on Figures 7D through 7J. At each pumping cycle, an amount of fluid is expelled from the active channel 420 through the orifice plate 424 into the common output chamber 428. From here on the fluid may be conducted in the desired direction, indicated by arrows 430.

Figure 13 shows the pump 400 of Figures 12A and 12B incorporated into an administration set 432. The body 401 of the pump 400 in this figure is shown in a fluid administration set 432. The pump 400 is driven by a driving signal from a pump controller 434 (similar to the controllers described above), by means of a cable 436 and connector 438, that sends electrical signals activating pumping action in the micropumps 403 (Figure 12B) by electrically stimulating the rods 402 (Figure 12B), causing movement thereof. The control device 434 may be a remotely located computer, such as one that is part of central nursing station, or a local computer/controller. Preferably, the dimensions of such a pump would be about 35 mm to 45 mm in length and about 7 mm in diameter. The fluid (i.e., medication) is drawn out of the fluid source, such as a bag in a fluid administration set (not shown) by capillary forces (in the direction of the arrow 440a) as described above and pumped to the patient in the direction indicated by arrow 440b. It is preferred that this pump 400 be disposable, as part of the disposable fluid administration set.

Figure 14 shows a microdosator 441, similar in construction to that shown in Figures 6A and 11, except that it incorporates the multichannel pump 400 of Figures 12A and 12B therein. The microdosator 441 is formed of a body member 444 with a removable cover for access to the pump 400. There is removable tip 446 on the microdosator 441, that may also include an orifice plate 448, similar to the orifice plate 424 (described for use with the pump 400 of Figures 12A and 12B above). The fluid to be dispensed may come from a fluid reservoir 450, or equivalent remote fluid source, through a conduit 451 that

preferably frictionally fits into the common chamber 418 (Figures 12A, 12B, and 13) of the pump 400. The fluid reservoir 450 is accessible through the removable cover. In the case of the remote fluid source, fluid from it flows to the microdosator 441 through an umbilical cable 452. The umbilical cable 452 may be combined with a cable that will carry the pump driving signal. The signal may be generated by a controller, such as a computer located close to the microdosator 441, or alternatively, a built-in controller with dial-on capabilities.

Figure 15 is a cross-sectional view of another embodiment of a pump 480. The pump 480 has two concentrically arranged rows of micropumps 481a, 481b, formed by arrays (rows) of rods 484, 496. The pump 480 is similar in construction and operation to the embodiment described in Figures 12A and 12B, except as indicated. The multiple row arrangement of micropumps 481a, 481b, provides for increased throughput, when compared to the embodiments detailed in Figures 12A, 12B and 13 above.

The first (inner) row of rods 484, forming the micropumps 481a, are of similar materials, electrosensitive materials, preferably poled (polarized) piezoelectric materials as described above, and of similar construction to the rods of Figures 12A and 12B (as described above). The rods 484 are poled (polarized) in a radially outward direction (as described in Figures 12A and 12B above) and attached to the innermost cylinder 488, of a porous material (as described above), and enclosed in the middle cylinder 492. The middle cylinder 492, that is also formed of a porous material (as described above), also serves as an inner cylinder for the second (outer) row of poled (polarized) rods 496 (poled in the same direction as the rods 484), that form the second series of micropumps 481b. The rods 496 are of similar materials and of similar construction to the rods 484 above, but may be differently sized. The outermost cylinder 500 closes the pump construction. It is preferred that dimensions of this pump 480 be similar to the pump 400 of Figures 12A, 12B and 13, except that the outer diameter is preferably approximately 9 mm-10 mm.

The construction given above creates a multiplicity of channels 504 and 508, which may have slight differences in size. In the course of the pump operation, the channels 504 and 508 are filled with fluid, delivered from a fluid source, such as a fluid bag, connected thereto. At each actuation cycle, the fluid is expelled from the active channels 504 and 508 through the orifices 512 and 516. The pump 480 is also suitable for use in microdosators (Figures 6A, 11 and 14), and disposable and non-disposable infusion apparatuses.

As shown in Figure 16, a fluid bag 532 includes the pump 400 (Figures 12A and 12B), but could also include the dual array pump 480 (Figure 15), with the interior of the fluid bag 532 having strips 534 of porous material, in accordance with the porous material described above. These strips 534 are firmly attached to the fluid bag 532 and serve as a fluid guide, as these strips 534 are in hydraulic communication with the fluid in the bag 532, allowing for fluid delivery to the patient (through the tubing 535 and needle 536), not dependent on gravity, regardless of fluid bag 532 position, above or below the patient, and fluid bag 532 orientation, vertical, horizontal or inclined. Although strips 534 of porous material are shown, the entire interior of the fluid bag 532 may be lined with this porous material if desired.

Figures 17A and 17B show a piezoelectric pump 537 in a fluid bag 538. The pump 537 and fluid bag 538 shown are similar in construction and operation to the pump 400 in the fluid bag 532 (Figure 16), except that porous material 540 (as described above), is preferably continuous with the pump 537, forming its outer cylinder 541 this outer cylinder 541 corresponding to the outer cylinder 408 of Figures 12A, 12B and 13. The outer cylinder 541 is such that it supplies fluid to the channels 542 of the micropumps 543. Alternately, a pump similar in construction and operation to the pump 480, as described above and shown in Figure 15 could also be substituted into the fluid bag 538 with the porous material arranged similarly. The layer of porous material 540 serves as a fluid guide, since it stays in permanent hydraulic communication with the liquid in the bag 538,

regardless of bag orientation, vertical, horizontal or inclined, and thus, allows for gravity independent fluid delivery.

The micropumps 543 are such that their channels 542 are created by rods 560, of electrosensitive material, preferably piezoelectric material (as described above), preferably poled (polarized) in the direction of the arrows (radially outward), that upon stimulation from electrical signals, from a controller (not shown), the rods 560 move such that fluid is expelled through orifices 562 in the face plate 564 into the common output chamber 568. The rods 560 are maintained in position by an inner cylinder 571 and the outer cylinder 541 in accordance with that disclosed above for the pumps 400, 480 (Figures 12A, 12B, 13 and 15). Plugs 572, 574 prevent uncontrolled penetration of the fluid into the common output chamber 568 and facilitate the enclosure of wires (not shown) that conduct electrical signals from the controller (not shown) into the rods 560 of the pump 537.

Figures 18A and 18B show an infusion pump 600 of multiple micropumps 601, similar to the micropumps 101 described and shown in Figure 4 above. This pump 600 is preferably disposable or implantable. This pump 600 has a stainless steel body 604 in which a set of recesses (cutouts) 608 has been made. An output chamber 612 extends from the interior of the body 604. This output chamber is covered by a faceplate 616, made of Teflon, capton, polyimide, glass or stainless steel, etc., into which orifices 620 have been made, in accordance with the techniques described above.

Opposite each of the recesses 608 are chambers 624 corresponding to each of each micropump 601, from which the fluid (e.g., medication) is pumped. These chambers 624 are in constant hydraulic communication with a reservoir 628, for holding the fluid (e.g. medication) prior to its being pumped. The chambers 624 and part of the reservoir 628 have walls 632 of porous material, in accordance with the porous material discussed above. The porous material serves as a drug delivery system to each of the recesses 608 of each of the

micropumps 601. An electrosensitive member 636, of a piezoelectric material (i.e., a single piezoelectric ceramic disc) in accordance with the piezoelectric materials disclosed above, is placed proximate to each chamber 624 and attached onto a membrane 640 (similar to the membrane 126 described in Figure 4 above) opposite the orifice 620 of each micropump 601. The membrane 640, also fixes the porous material walls 632 in place, and this membrane 640 is covered and enclosed by a lid 644. This lid 644 prevents interaction between fluid in the pump 600 and the current conducting parts (not shown), so as to create a closed compartment 648 into which the driving electronics (not shown) (that operate similar to the above detailed controllers) for moving the electrosensitive members 636 and battery (not shown) for these driving electronics are placed. Each individual micropump 601 is operated by a driving signal(s), preferably an electrical signal(s), generated by the driving electronics, that can be controlled by the user. The driving electronics are such that the user may increase or decrease the drug delivery rate by switching on one or more micropumps 601 as well as switching on or off additional micropumps 601, as desired. Alternatively, the electrosensitive member 636 may be operated at a higher than rated frequency. The compartment 648 may be accessed for battery replacement.

The pump 600 operates as a driving signal is sent to one or more of the electrosensitive members 636. The signal activates the electrosensitive members 636, that accordingly bend the respective portion of the membrane 640. During the contraction cycle of the electrosensitive members 636, the membrane 640 expels the fluid (i.e., the medication) through the orifice 620, and during the expansion cycle, it creates pressure that pulls in the liquid from the recess 608, to which it is fed from the reservoir 628. The reservoir 628 is the space created by the external packaging 652 of the pump and its lid 656. The body 604 is attached to the packaging 652 and the space between them creates the common output chamber 660, into which the fluid (i.e., medication) drug is expelled by successive pumping actions of the electrosensitive members 636.

The fluid (i.e., medication) leaves the pump 600 (for delivery to the patient) through the output catheter 612. This catheter 612 is separated from the output chamber 660 by a one-way valve 664. The pump 600 is refillable with fluid (i.e., medication), through an input catheter 665 attached to the lid 656. The catheter 665 is separated from the reservoir 628 by a one-way valve 668. These one-way valves 664, 668 may be of any of the type discussed above, i.e., check valves (as described above).

The pump 600 preferably has an outside diameter (of the packaging 652) of approximately 30 mm and a thickness of approximately 8 mm to 9 mm. The reservoir 628 preferably has a storage volume of approximately 4.5 ml to 5 ml., depending on the number of micropumps 601 within the pump 600.

Figure 19 shows an alternate pump 600', also preferably disposable and implantable, similar in all aspects to the pump 600 (Figures 18A and 18B), except that this pump 600' includes a bellows 670. This bellows 670 serves as a constant pressure mechanism to provide a constant fluid (i.e., medication) delivery rate, regardless of the ambient pressure. The bellows 670 is attached to the lid 644 and the membrane 640. Should the ambient pressure change, the volume of the compartment 648 will change accordingly by expanding or contracting the bellows 670.

The pumps 600, 600' may also be designed to eject fluid into the ambient, by leaving the orifices 620 open (eliminating the output catheter 612, common output chamber 660 and one way valve 664). Because of the close proximity of the orifices 620, when they are all operated simultaneously, a moving mist is created of the particular fluid (i.e., medication) in an accurate dose.

Figures 20A and 20B show an inhalator 700 formed of a number of micropumps 704 arranged in a grid pattern. Each micropump 704 is similar in construction to the micropumps 101 shown in Fig. 4 (and detailed above). Within the inhalator 700 is a chamber 708 formed of a closed, hexagonally-shaped

channel on the back of the body 710. Round recesses 712 are also arranged in this hexagonal pattern. Opposite each of the recesses 712 is an electrosensitive member 716 (of the materials disclosed above), on a portion of a membrane 717. The electrosensitive members 716 are controlled by mechanisms similar to those disclosed in Figures 4, 7A-7N, 8A, 8B, 18A, 18B and 19 above. A orifice plate 720 is attached to the front of the body 712, in which orifices 724 are made, in accordance with the methods detailed above. The electrical connection of the electrosensitive members 716 to the control mechanisms is similar to that shown in Figure 4. Each of the input chambers 708 is connected by a fitting 728 to a source of fluid (i.e., medication) (not shown) that is dispensed by each of the micropumps 704 when they are activated. The fittings 728 may be connected to a common reservoir or to separate reservoirs that provide an instant mixture of fluids (i.e., medications) in variable dosages. A series of openings 732 in the tubes 733 are arranged in a grid pattern similar to that of the orifices 724. The tubes 733 terminate in a common area, preferably extending through the body 710, and can be connected, by fittings or the like (not shown) to a source of air or oxygen. Alternately, the tubes 733 may be open to the ambient environment, serving to transport ambient air to the side of the body 710 where the fluid will be released. The air and/or oxygen from the source, or alternately the ambient air, creates a flow which further picks up the drug and carries it to the patient.

Figure 21 is an inhalator 750 that dispenses fluid by a piezoelectric effect. The pump 754 is contained within a PVC envelope 756, and is constructed in accordance with the pumps 400, 480 of Figures 12A, 12B and 15, with the controlling electronics for pumping the fluid in accordance with those described for the pumps 600, 600' and inhalator 700 (above). The envelope 756 includes a reservoir 758 that supplies fluid (i.e., medication). Ambient air (or air or oxygen from an outside source) is supplied through the openings 762. It is produced and operated like the pump shown in Figures 12 and 15.

While embodiments of the present invention have been described so far as to enable one of skill in the art to practice the present invention, the preceding

description is intended to be exemplary and should not be used to limit the scope of the invention. The scope of the invention should be determined by reference to the following claims.

What is claimed is:

1. A microdosing pump comprising:

a chamber for receiving fluid;

a plurality of channels in communication with said chamber, each of said channels including at least one opening for the outflow of fluid;

a membrane enclosing at least a portion of said chamber;

a plurality of electrosensitive members, each of said electrosensitive members in communication with at least a portion of said membrane, and positioned in correspondence with each of said channels, each of said electrosensitive members being movable in response to an electrical signal;

means for controlling at least one of said plurality of electrosensitive members independent of at least one other of said plurality of said electrosensitive members.

2. The microdosing pump of claim 1, wherein said controlling means includes means for producing an electrical signal on each one of said plurality of said electrosensitive members.

3. The microdosing pump of claim 1, wherein said plurality of channels are formed from a first plate and said at least one opening in each of said channels is formed at a location corresponding each of said plurality of channels on a second plate.

4. The microdosing pump of claim 1, wherein each of said electrosensitive elements rests on said at least a portion of said membrane.

5. The microdosing pump of claim 2, wherein said electrosensitive member includes a piezoelectric element.

6. A microdosing pump comprising:

a body portion including at least one opening for the inflow of fluid;

a first member within said body portion including a plurality of channels extending therethrough;

a second member in communication with said first member, said second member including a plurality of openings, said at least one of said plurality of openings positioned in correspondence with each of said plurality of channels;

a membrane enclosing at least a portion of said body portion;

a plurality of electrosensitive members, each of said electrosensitive members in communication with at least a portion of said membrane, and positioned in correspondence with each of said channels, each of said electrosensitive members being movable in response to an electrical signal; and

means for controlling said electrosensitive members.

7. The microdosing pump of claim 6, wherein said controlling means include means for operating at least one of said electrosensitive members independently of at least one other of said electrosensitive members.

8. The microdosing pump of claim 7, wherein each of said plurality of said electrosensitive members includes a piezoelectric element.

9. The microdosing pump of claim 8, wherein said controlling means additionally include means for producing an electrical signal.

10. The microdosing pump of claim 6, wherein said controlling means include means for operating said plurality of electrosensitive members simultaneously.

11. A microdosing pump comprising:

a body portion including a chamber, said chamber including a first port and a second port;

a first fluid pathway in communication with said first port for carrying fluid into said chamber, said first pathway including at least one subchannel for storing fluid;

a second fluid pathway in communication with said second port for carrying fluid from said chamber, said second pathway including at least one subchannel for storing fluid;

a membrane attached to said body portion enclosing at least a portion of said chamber;

means for controlling fluid flow through said channel, said fluid flow controlling means including at least one electrosensitive member in communication with at least a portion of said membrane; and

means for controlling said at least one electrosensitive member.

12. The microdosing pump of claim 11, wherein said first and second ports and said subchannels of said first and second fluid pathways are within said body portion.

13. The microdosing pump of claim 12, wherein said first port includes a recessed portion, extending outward from said chamber toward said subchannel.

14. The microdosing pump of claim 12, wherein said second port includes a recessed portion, extending inward from said chamber toward said subchannel.

15. The microdosing pump of claim 12, wherein said first port includes a recessed portion, extending inward from said chamber toward said subchannel.

16. The microdosing pump of claim 12, wherein said second port includes a recessed portion, extending outward from said chamber toward said subchannel.

17. The microdosing pump of claim 15, wherein a fluid flow inhibiting member seats within said recessed portion, and a means for retaining said fluid flow inhibiting member within said recessed portion.

18. The microdosing pump of claim 16, wherein a fluid flow inhibiting member seats within said recessed portion, and a means for retaining said fluid flow inhibiting member within said recessed portion.

19. The microdosing pump of claim 17, wherein said fluid flow inhibiting member includes a ball and said retaining means includes an elastomeric net.

20. The microdosing pump of claim 18, wherein said fluid flow inhibiting member includes a ball and said retaining means includes an elastomeric net.

21. The microdosing pump of claim 12, wherein said second fluid pathway includes a check valve in communication with said subchannel and said subchannel of said second fluid pathway includes a flexible member movable between unstressed and stressed positions.

22. The microdosing pump of claim 21, wherein said check valve is biased to a predetermined pressure, and said flexible member is coordinated with said check valve, whereby when the pressure in said subchannel reaches said predetermined pressure, said flexible member returns to said unstressed position forcing open said check valve.

23. The microdosing pump of claim 22, wherein said predetermined pressure is approximately the pressure of a mammalian blood vessel.

24. The microdosing pump of claim 11, wherein said at least one electrosensitive member includes a piezoelectric element.

25. A microdosing apparatus comprising:

a container member, said container member including a reservoir portion in communication with a fluid receiving space, said fluid receiving chamber in communication with a fluid outlet port; and

a microdosing pump within said body member intermediate said reservoir portion and said fluid receiving chamber, said pump comprising:

a chamber for receiving fluid in communication with said fluid reservoir portion;

a plurality of channels, each of said plurality of said channels having a first end and a second end, said first end of each of said plurality of said channels in communication with said chamber, each of said channels including at least one opening for the outflow of fluid at said second end, said second end of each of said plurality of said channels in communication with said fluid receiving space;

a membrane enclosing at least a portion of said chamber;

a plurality of electrosensitive members, each of said electrosensitive members in communication with at least a portion of said membrane, and positioned in correspondence with each of said channels, each of said electrosensitive elements being movable in response to an electrical signal; and

means for controlling at least one of said plurality of electrosensitive members independent of at least one other of said plurality of said electrosensitive members.

26. The microdosing apparatus of claim 25, wherein said container member includes means for gripping by an operator.

27. The microdosing apparatus of claim 25, wherein said container member includes a bag.

28. The microdosing apparatus of claim 25, wherein said controlling means includes means for producing a voltage on each one of said plurality of said electrosensitive members.

29. The microdosing apparatus of claim 25, wherein said plurality of channels are formed from a first plate and said at least one opening in each of said channels is formed at a location corresponding each of said plurality of channels on a second plate.

30. The microdosing apparatus of claim 25, wherein each of said electrosensitive elements rests on said at least a portion of said membrane.

31 The microdosing pump of claim 25, wherein said electrosensitive member includes a piezoelectric element.

32. A microdosing apparatus comprising:

a body portion including a fluid receiving opening and a fluid collection area;

a pump adapted to fit at least within said body portion, said pump including a plurality of rods of an electrosensitive material movable in response to electrical signals, and including,

a chamber for receiving fluid in communication with said fluid receiving opening;

at least one channel in fluid communication with said chamber and said fluid collection area, said at least one channel formed intermediate each of said rods of said plurality of rods; and

means for controlling the movement of said rods.

33. The microdosing pump of claim 32, wherein said at least one channel includes a plurality of channels, and at least one of said plurality of channels is intermediate adjacently disposed rods of said plurality of rods.

34. The microdosing pump of claim 33, additionally comprising:

a plate member intermediate said first member and said fluid receiving area, said plate member including a plurality of openings, at least one opening of said plurality of openings corresponding to each one of said plurality of channels.

35. The microdosing pump of claim 34, additionally comprising a partitioning member intermediate said plurality of channels, said partitioning member being of a porous material.

36. The microdosing pump of claim 35, wherein said partitioning member extends intermediate said chamber for receiving fluid and said plate member.

37. The microdosing pump of claim 33, wherein said controlling means includes means for producing electrical signals.

38. A microdosing pump comprising:

a body portion including a fluid receiving opening in communication with a fluid storage area;

a member adapted to fit at least partially within said body portion, said member including a plurality of rods, said rods of an electrosensitive material and arranged around said fluid storage area, at least one of said rods of said plurality of rods forming at least one channel intermediate at least another one of said rods of said plurality of rods; and

means around said fluid storage area for permitting fluid flow between said fluid storage area and said channels, said fluid flow means intermediate said fluid storage area and said channels.

39. The microdosing pump of claim 38, wherein said fluid storage area includes a first end in communication with said fluid receiving opening and a second end adapted to receive a removably attachable plug.

40. The microdosing pump of claim 39, wherein said at least one channel includes a plurality of channels, at least one of said plurality of channels intermediate adjacent rods of said plurality of rods.

41. The microdosing pump of claim 40, wherein said body portion is cylindrical in shape and includes a peripheral wall, and said member is within said body portion, said member including means contacting said peripheral wall of said body portion for retaining said member within said body portion.

42. The microdosing pump of claim 41, additionally comprising a plate in communication with said member, said plate adapted to fit within said body portion, said plate including a plurality of openings, at least one of said openings of said plurality of openings corresponding to each of said channels of said plurality of channels.

43. The microdosing pump of claim 42, wherein said peripheral wall includes an indented portion having a surface substantially perpendicular to said peripheral wall, said plate on said surface and said member on said plate.

44. An inhalation apparatus comprising:

a container including at least one reservoir and at least one fluid outlet port; means for transporting gas to an area proximate said fluid outlet port; and

a microdosing pump within said container, said pump comprising:

a chamber for receiving fluid in communication with said at least one reservoir;

a plurality of channels, each of said plurality of said channels having a first end and a second end, said first end of each of said plurality of said channels in communication with said chamber, each of said channels including at least one opening for the outflow of fluid at said second end, said second end of each of said plurality of said channels in communication with said fluid outlet port;

a membrane enclosing at least a portion of said chamber;

a plurality of electrosensitive members, each of said electrosensitive members in communication with at least a portion of said membrane, and positioned in correspondence with each of said channels, each of said electrosensitive elements being movable in response to an electrical signal; and

means for controlling at least one of said plurality of electrosensitive members independent of at least one other of said plurality of said electrosensitive members.

45. The apparatus of claim 44, wherein said controlling means includes means for producing electrical signals.

46. The apparatus of claim 44, wherein said gas transporting means includes a conduit extending through said container.

47. The apparatus of claim 44, wherein said gas transporting means include means for attaching to a gas supply source.

48. An inhalation apparatus comprising:

a housing having a first side and a second side and means for allowing the passage of gases between said first and second sides;

a fluid storage area within said housing; and

a pumping member adapted to fit at least partially within said housing portion, said member including a plurality of rods, said rods of an electrosensitive material movable in response to an electrical signal, and arranged around said

fluid storage area, at least one of said rods of said plurality of rods forming at least one channel intermediate at least another one of said rods of said plurality of rods;

means around said fluid storage area for permitting fluid flow between said fluid storage area and said channels, said fluid flow means intermediate said fluid storage area and said channels; and

means for controlling said rods.

49. The apparatus of claim 48, wherein said control means include means for producing electrical signals.

50. A microdosing apparatus comprising:

a body member including a chamber for receiving fluid and plurality of channels, said plurality of channels including at least a first series of channels and a plurality of second series of channels, said chamber in communication with at least said first series of channels;

each of said second series of channels including, at least one of said channels of said first series of channels in communication with at least one additional channel of said plurality of channels, and at least one fluid outlet port, said fluid outlet port in communication with said at least one additional channel;

at least one membrane in communication with said body member;

a plurality of electrosensitive members, at least one of said electrosensitive members in communication with at least a portion of said at least one membrane, and positioned in correspondence with each of said channels, each of said electrosensitive members being movable in response to an electrical signal;

means for controlling said plurality of electrosensitive members.

51. The microdosing pump of claim 50, wherein said each of said second series of channels includes, one channel of said first series of channels, and said at

least one additional channel of said plurality of channels includes two channels connected to each other.

52. The microdosing pump of claim 51, additionally comprising at least one common reception area and wherein, each of said fluid outlet ports empty into said at least one common reception area.

53. The microdosing pump of claim 52, wherein said at least one common reception area includes one common reception area.

54 The microdosing apparatus of claim 52, wherein said at least one common reception area includes at least a first portion and a second portion, at least one of said fluid outlet ports empties into said first portion and at least one of said fluid outlet ports empties into said second portion.

55. The microdosing apparatus of claim 54, wherein at least one channel of said first series of channels includes at least one inlet port.

56. The microdosing apparatus of claim 52, additionally comprising:

at least one supplemental body member, said at least one supplemental body member including at least one channel therein, said channel in communication with a fluid inlet port and a fluid outlet port;

at least one membrane in communication with said body member;

at least one electrosensitive member in communication with at least a portion of said at least one membrane, and positioned in correspondence with said at least one channel, said at least one electrosensitive member being movable in response to an electrical signal; and

said fluid outlet port in communication with said at least one common reception area.

57. A microdosing apparatus comprising:

a plurality of channels connected by a fluid passage, said plurality of channels including at least one fluid inlet port and at least one fluid outlet port;

a body member for enclosing said channels at least in part;

at least one membrane in communication with said body member;

a plurality of electrosensitive members, at least one electrosensitive member in communication with at least a portion of said at least one membrane, and positioned in correspondence with each of said plurality of channels, said at least one electrosensitive member being movable in response to an electrical signal; and

means for controlling said electrosensitive members, such that said pressure of the fluid leaving said fluid outlet port is substantially proportional to the sum of the pressures of the channels through which the fluid has passed.

58. The apparatus of claim 57, wherein said plurality of channels includes at least two channels.

59. The apparatus of claim 58, wherein said at least two channels includes three channels.

60. A method of fluid delivery comprising:

a. providing a pump, said pump comprising:

a body portion including at least one opening for the inflow of fluid;

a first member within said body portion including a plurality of channels extending therethrough;

a second member in communication with said first member, said second member including a plurality of openings, said at least one of said plurality of openings positioned in correspondence with each of said plurality of channels;

a membrane enclosing at least a portion of said body portion;

a plurality of electrosensitive members, each of said electrosensitive members in communication with at least a portion of said

membrane, and positioned in correspondence with each of said channels, each of said electrosensitive members being movable in response to an electrical signal; and

means for controlling said electrosensitive members; and

b. operating said control means by providing electrical signals to at least a plurality of said electrosensitive members concurrently.

61. The method of claim 60, further comprising operating said at least a plurality of said electrosensitive members at different frequencies.

62. The method of claim 61, wherein said pump additionally comprises a plate having a plurality of orifices, said plate covering at least a portion of said body portion in communication with at least one of said plurality of orifices positioned in correspondence to each of said plurality of channel, at least one of said orifices of a different diameter than at least one other of said orifices;

and said operating step additionally comprises providing electrical signals to at least a plurality of said electrosensitive members whose corresponding channels correspond to orifices, at least one of said orifices of a different diameter than at least one other of said orifices.

63. The method of claim 62, further comprising operating said at least a plurality of said electrosensitive members at different frequencies.

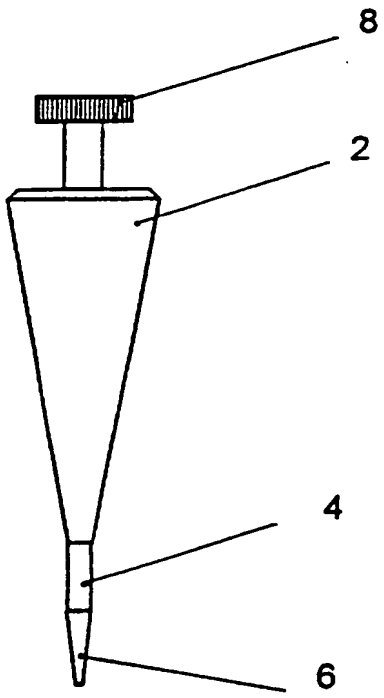


Fig. 1A. Prior Art

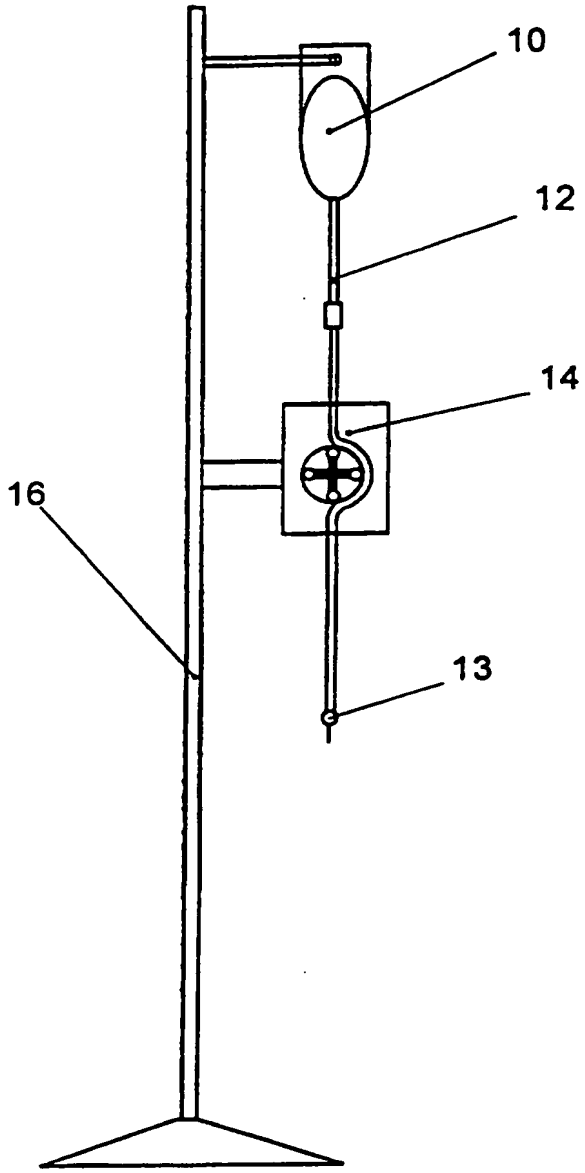


Fig. 1B. Prior Art

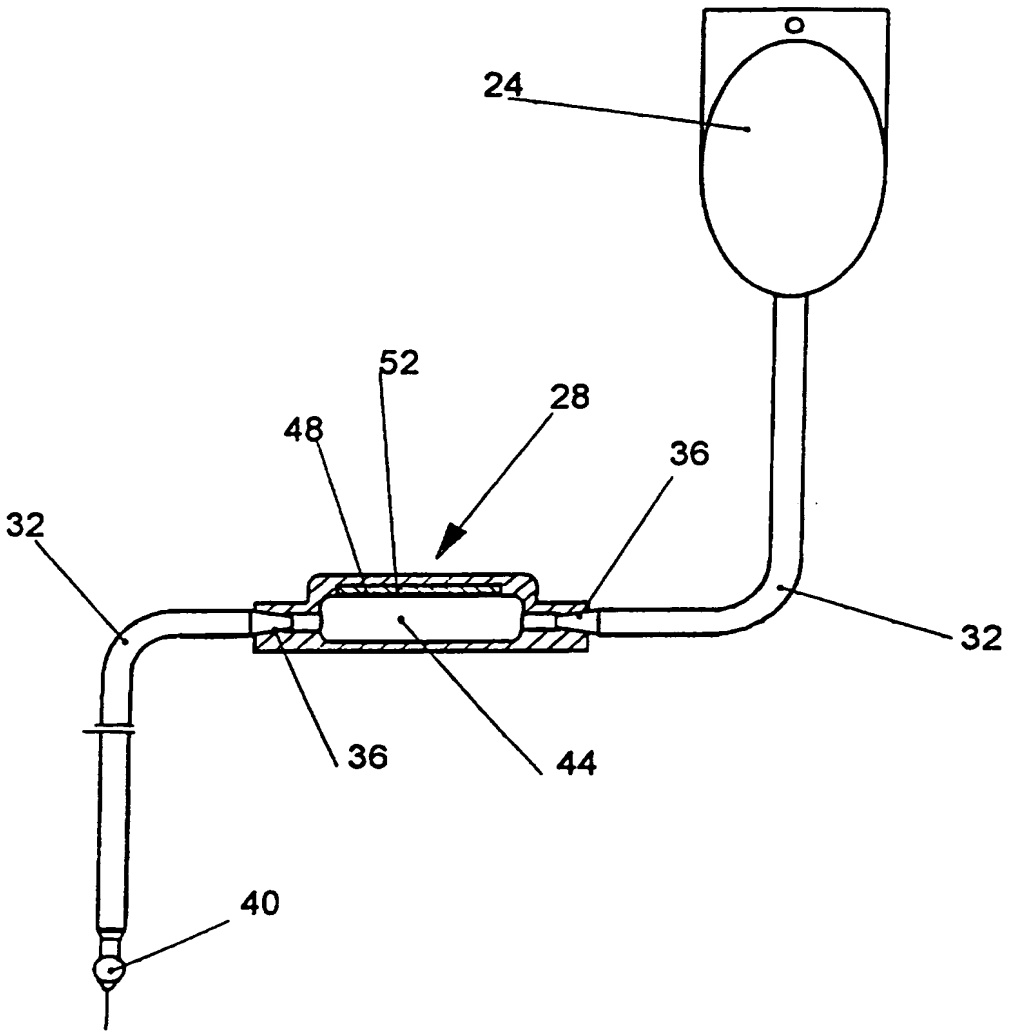


Fig. 2. Prior Art

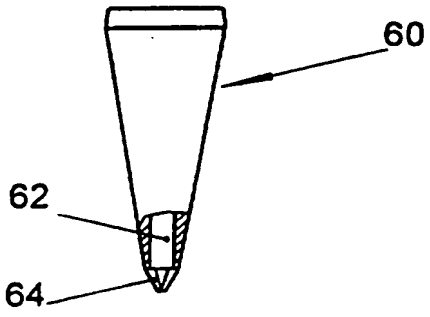


Fig. 3A.

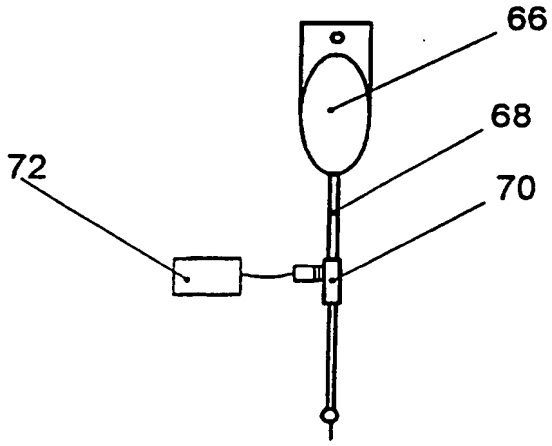


Fig. 3B.

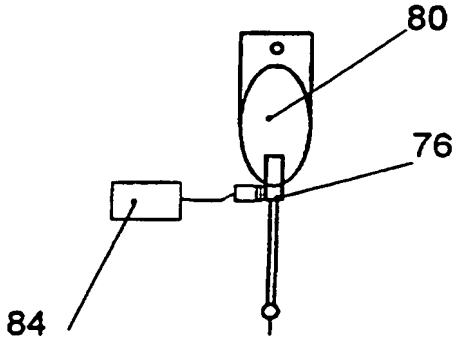


Fig. 3C.

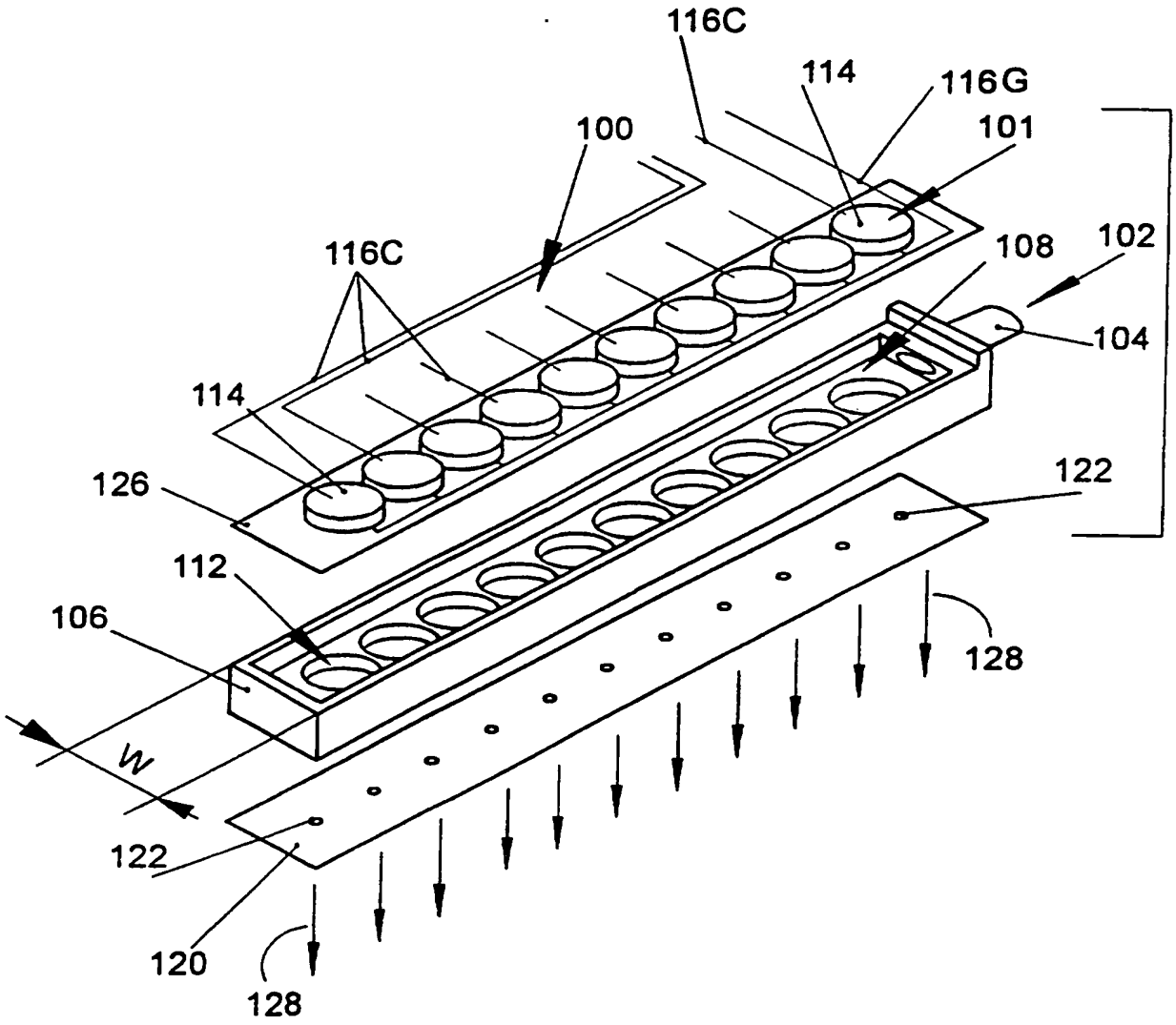

116C
114
116G
100
101
116C
108
102
104
114
126
122
112
106
128
W
122
120
128

Fig. 4

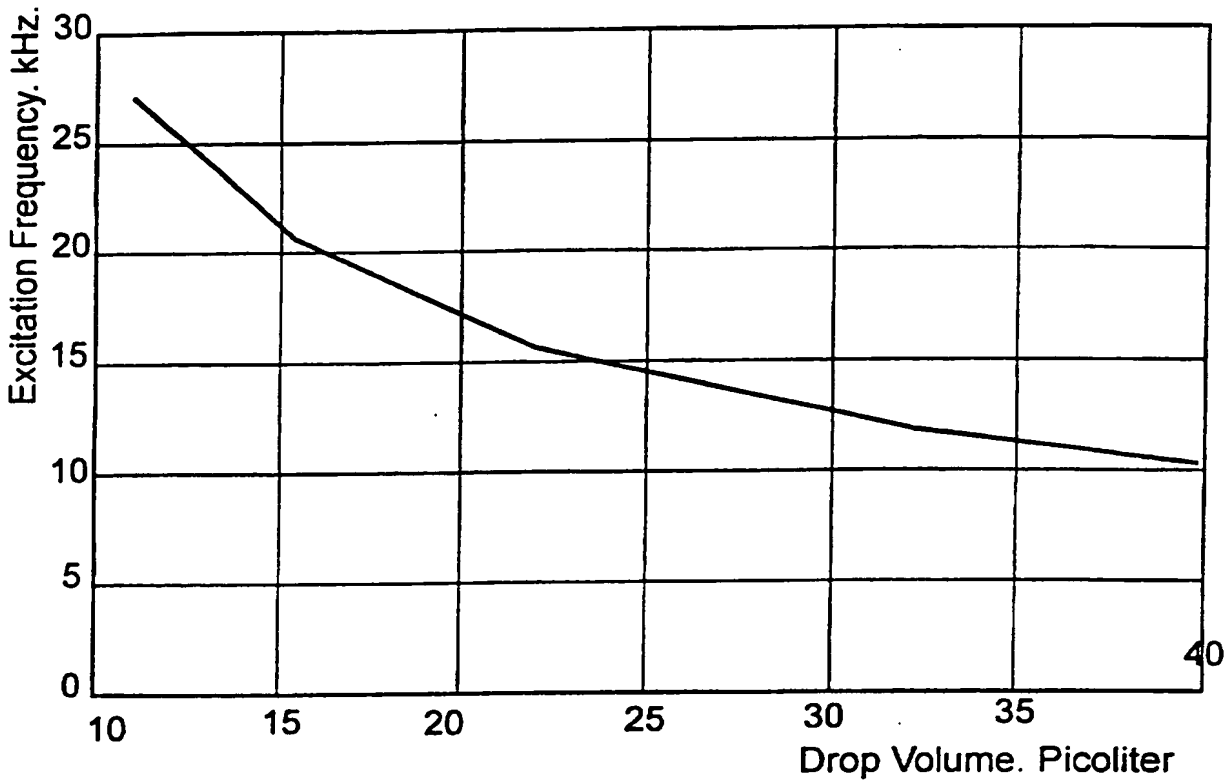

Excitation Frequency. kHz.
30
25
20
15
10
5
0
10
15
20
25
30
35
40
Drop Volume. Picoliter

Fig. 5A

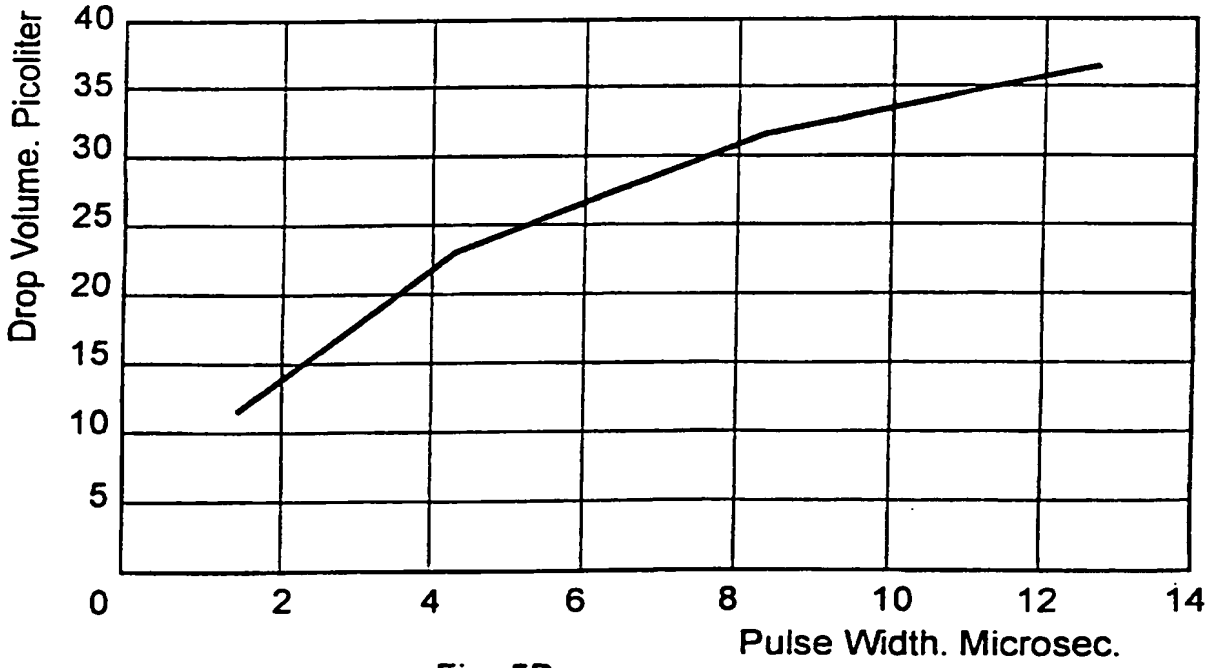

Drop Volume. Picoliter
40
35
30
25
20
15
10
5
0
2
4
6
8
10
12
14
Pulse Width. Microsec.

Fig. 5B

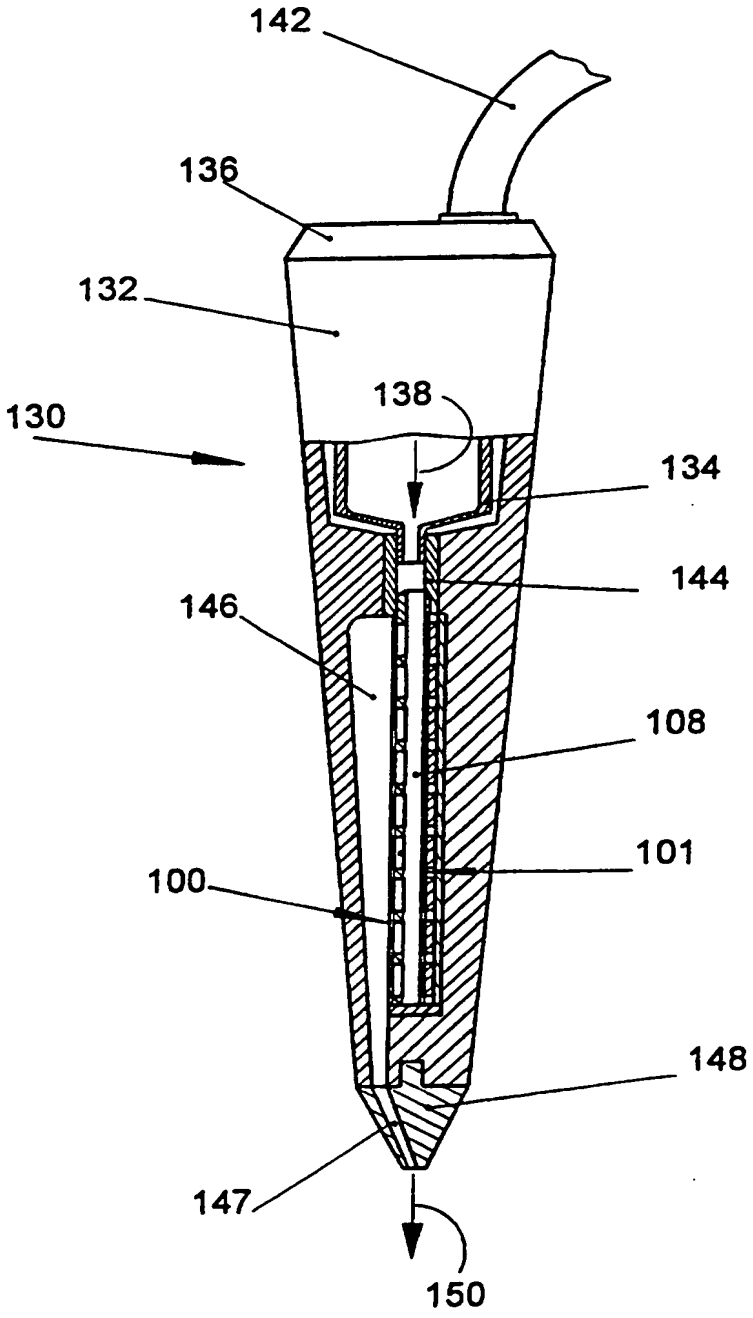


Fig. 6A

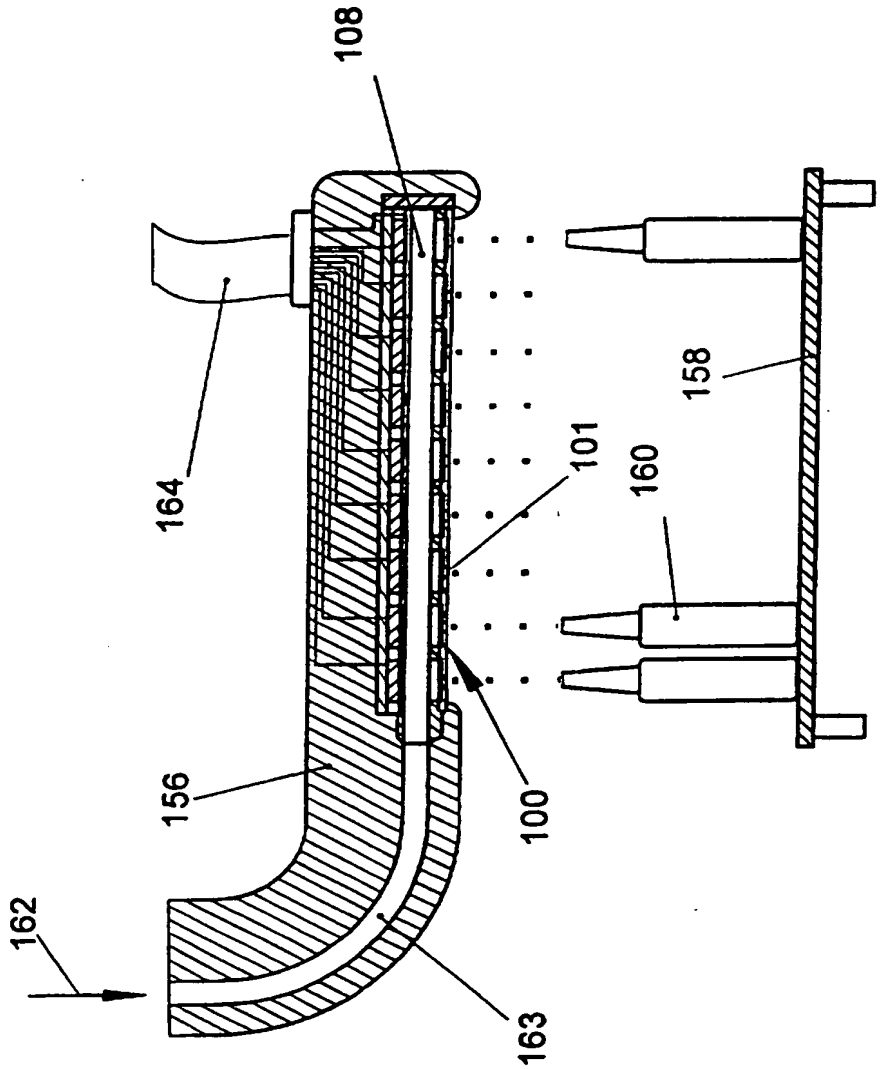


Fig. 6B.

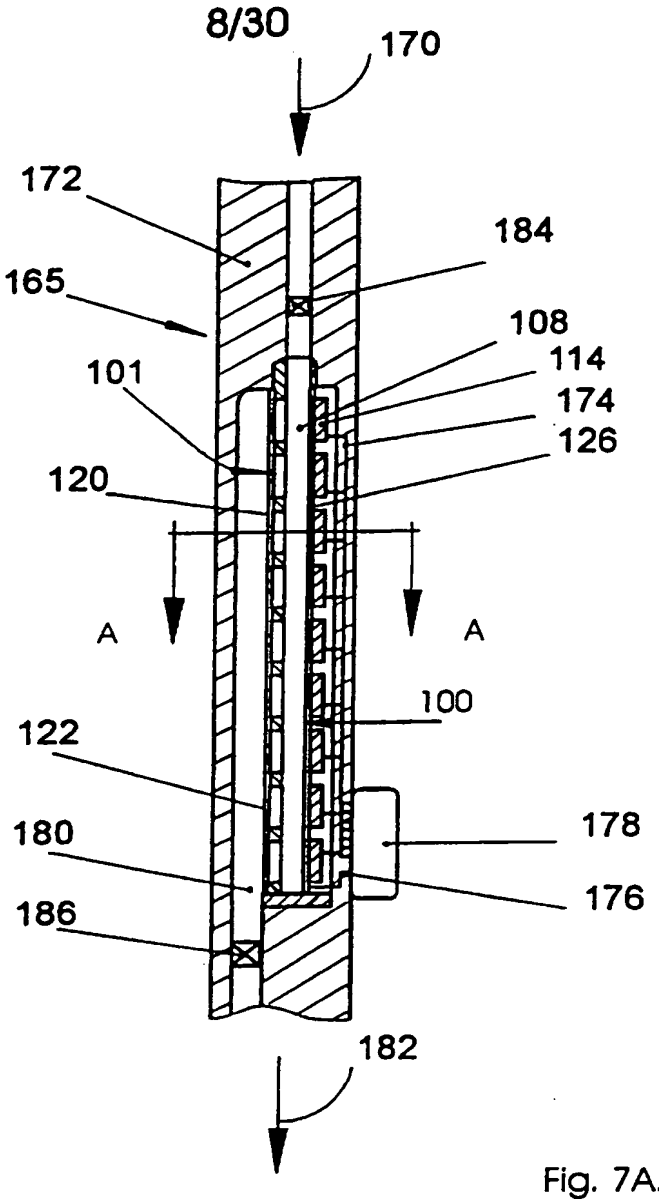

170
172
184
165
108
114
101
174
126
120
A
A
100
122
178
180
176
186
182

Fig. 7A.

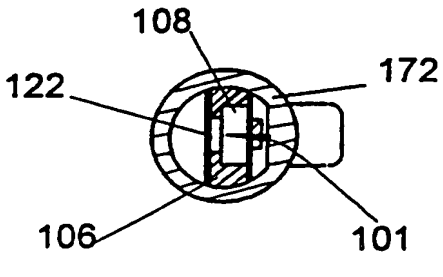

108
172
122
106
101

Fig. 7B.

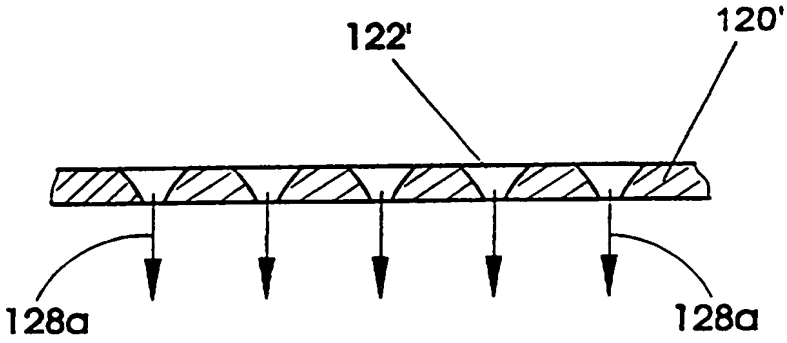


Fig. 7C.

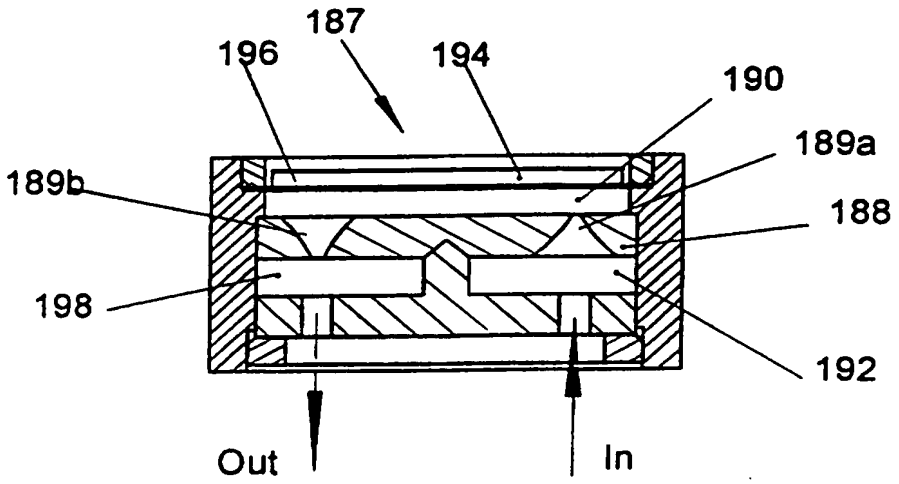

187
196
194
190
189a
189b
188
198
192
Out
In

Fig. 7D.

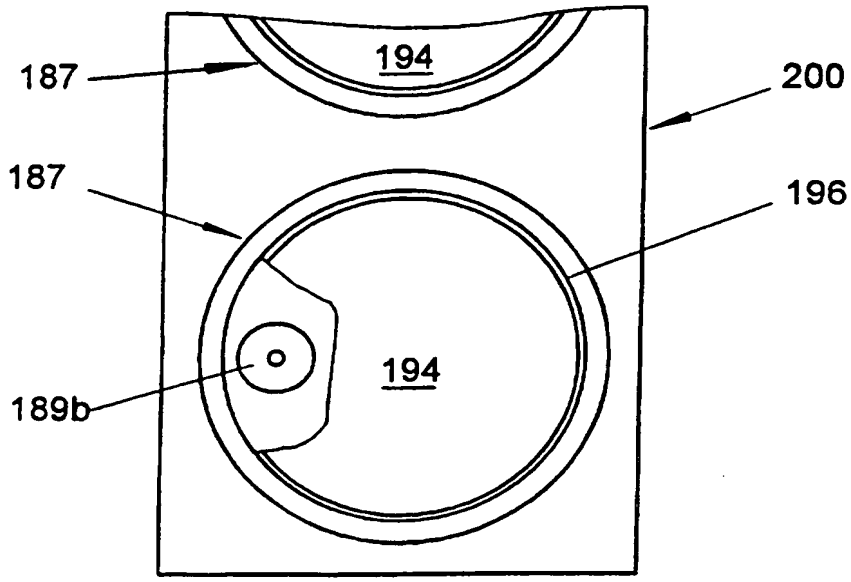
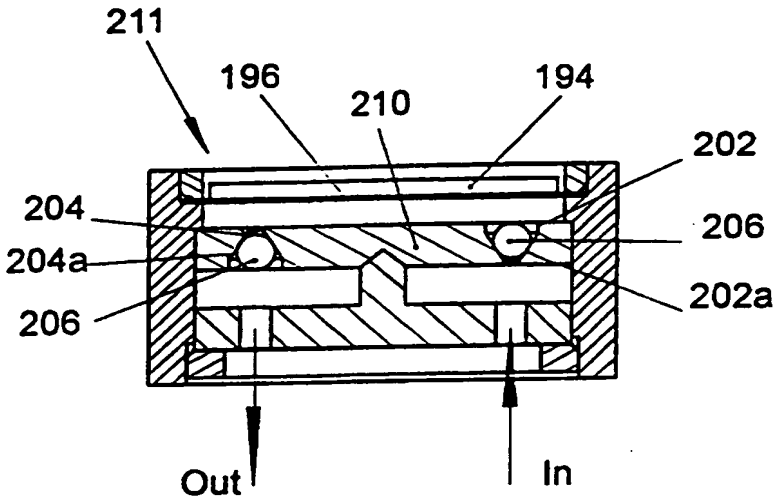

194
187
200
187
196
194
189b

Fig. 7E.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202a
206
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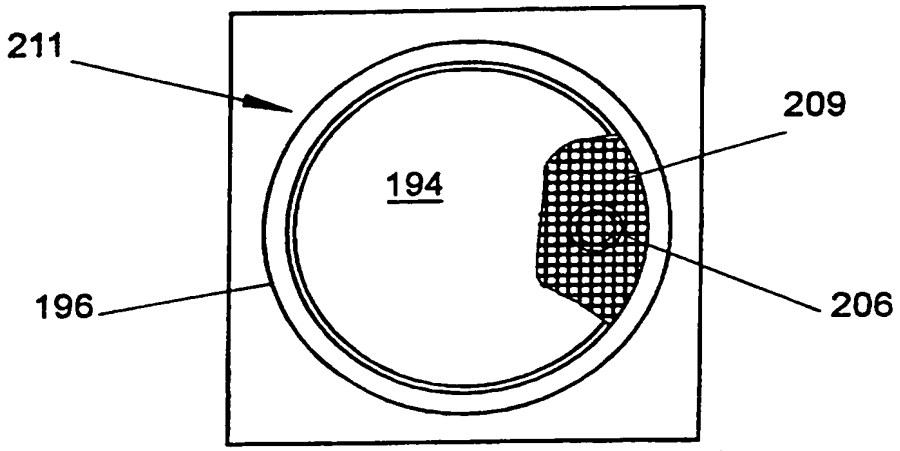
Fig. 7F.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206

Fig. 7G.

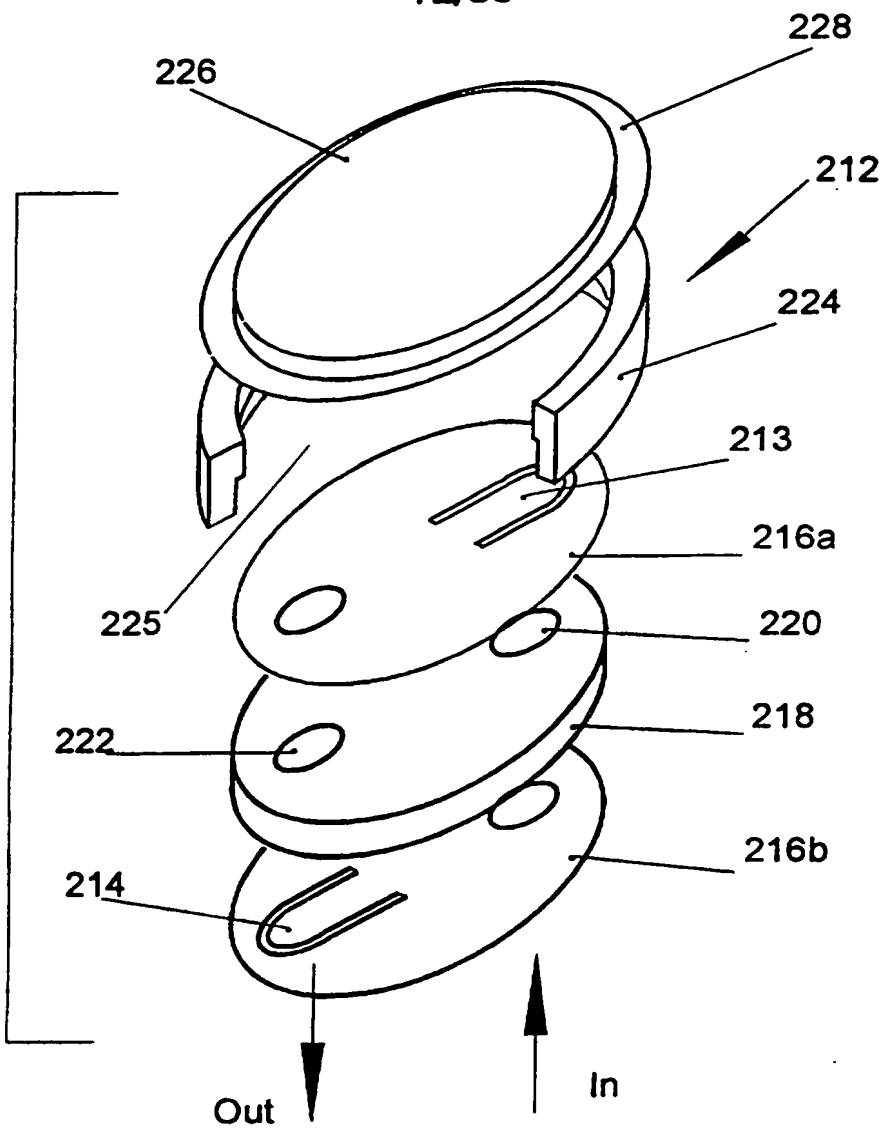


Fig. 7H.

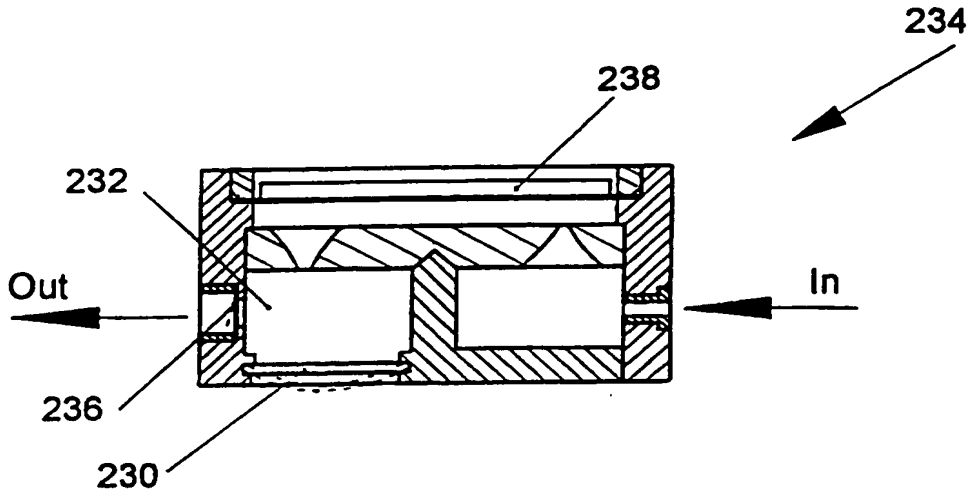


Fig. 7I.

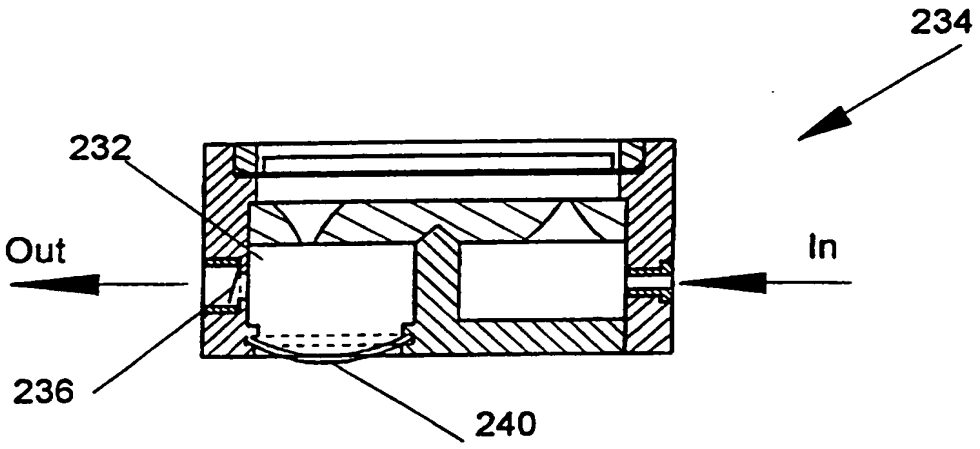


Fig. 7J.

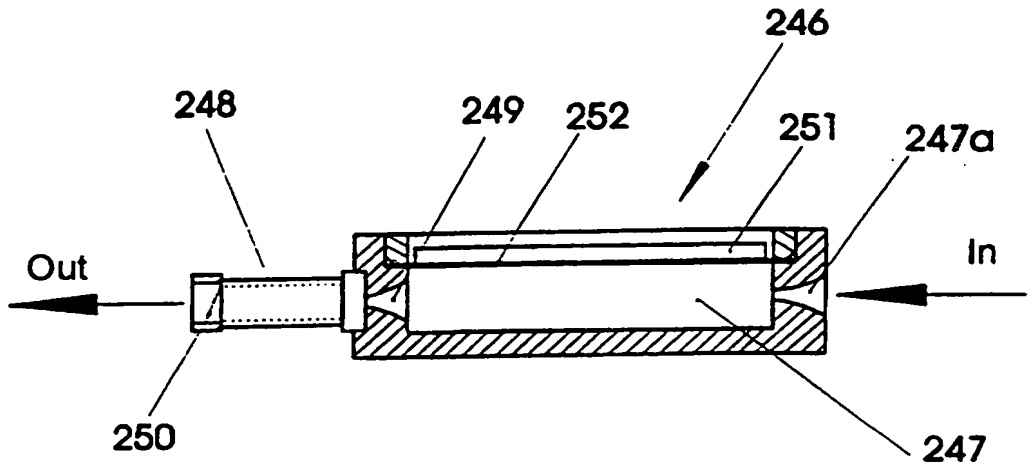


Fig. 7K.

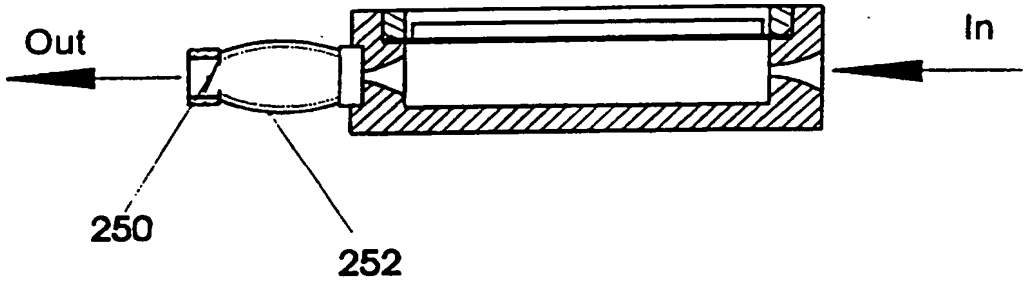
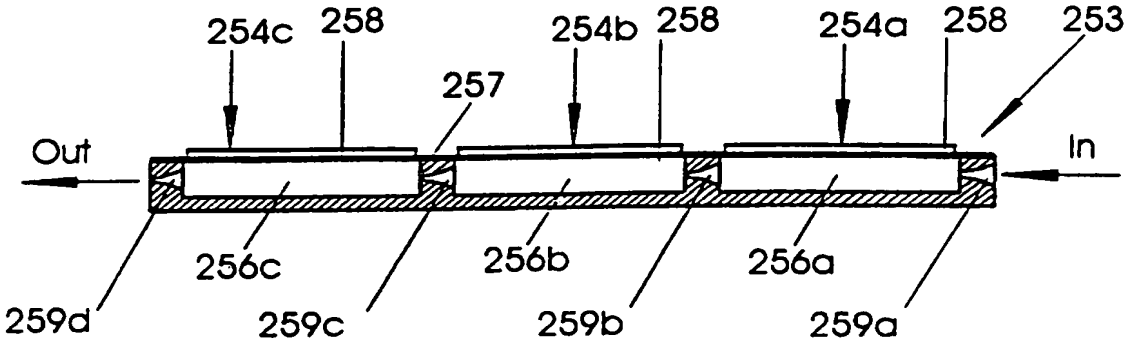


Fig. 7L.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258
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254a
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253
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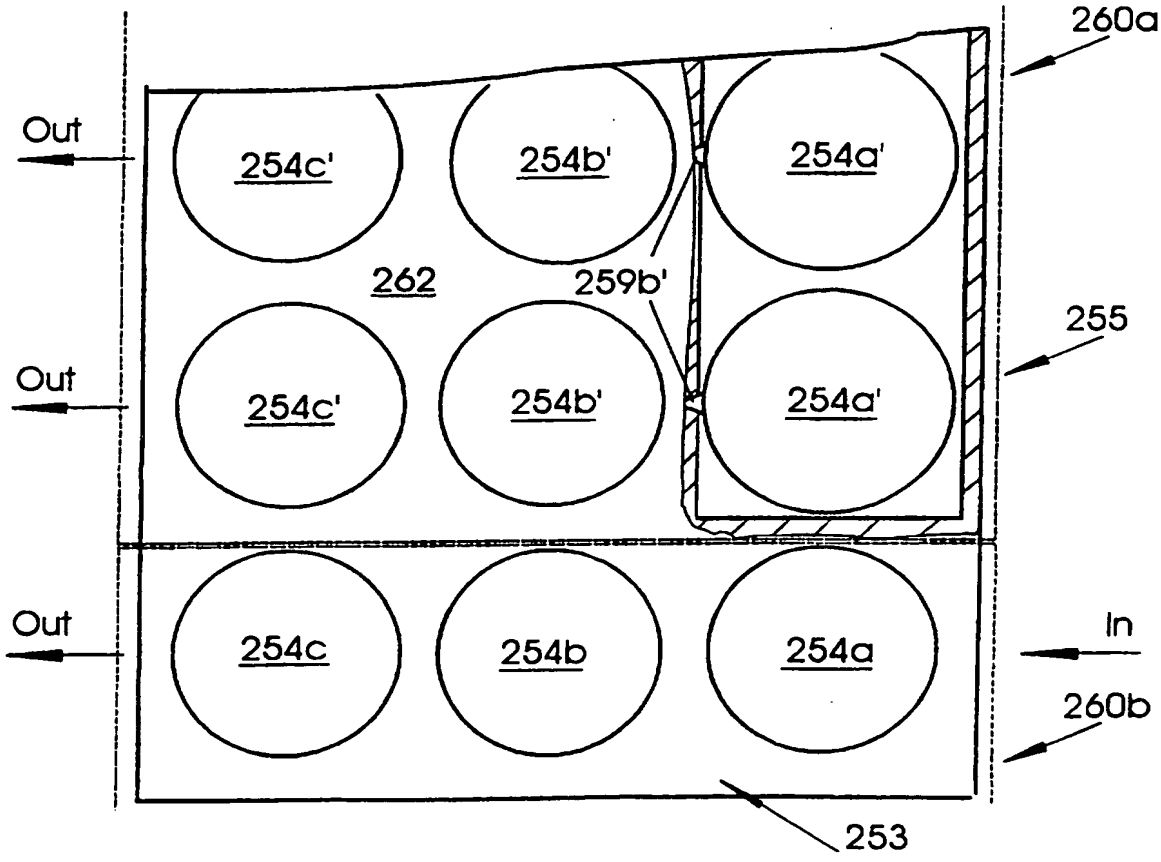
256b
256a
259d
259c
259b
259a

Fig. 7M.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254b'
254a'
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259b'
255
Out
254c'
254b'
254a'
Out
254c
254b
254a
In
260b
253

Fig. 7N.

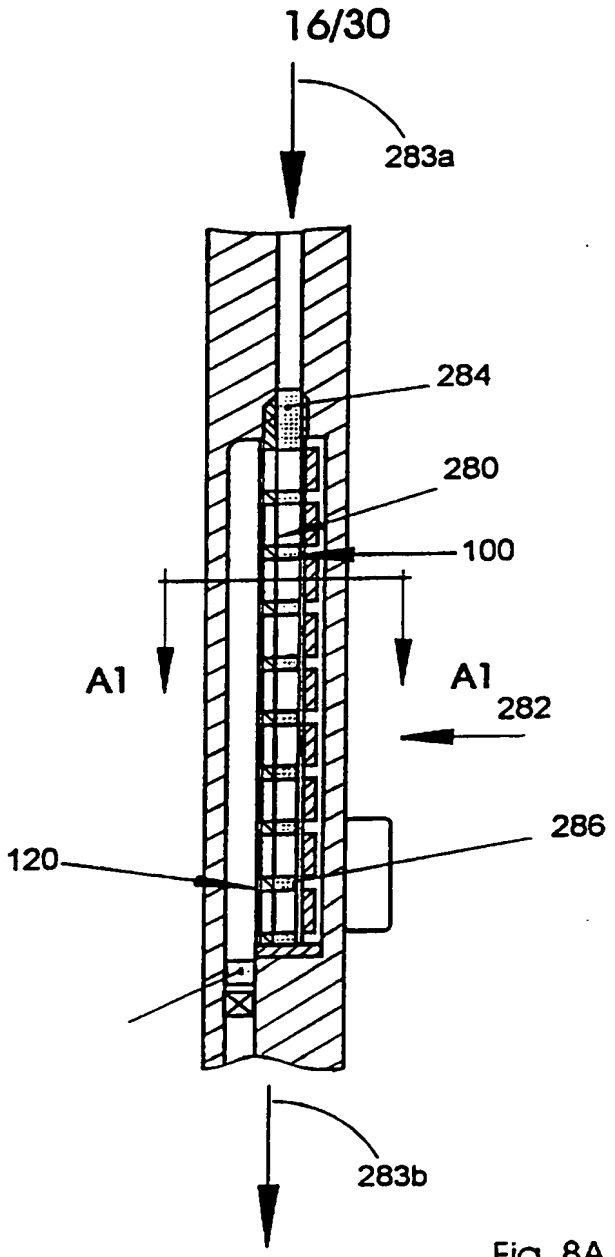


Fig. 8A.

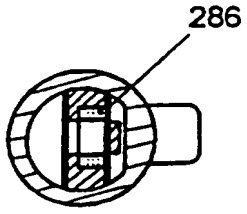
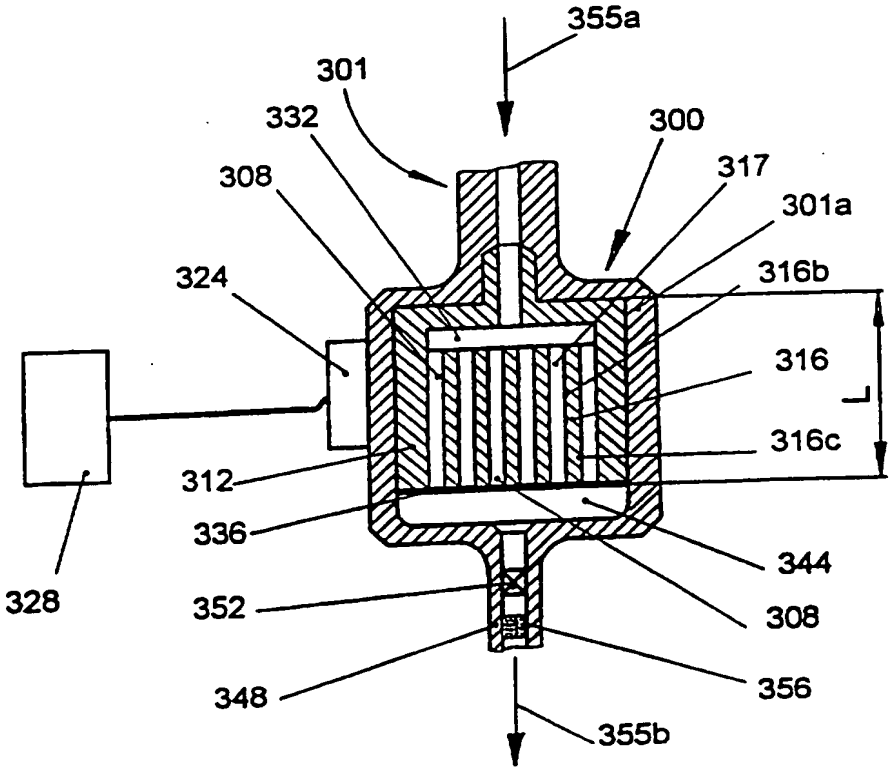


Fig. 8B.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317
301a
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316b
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316c
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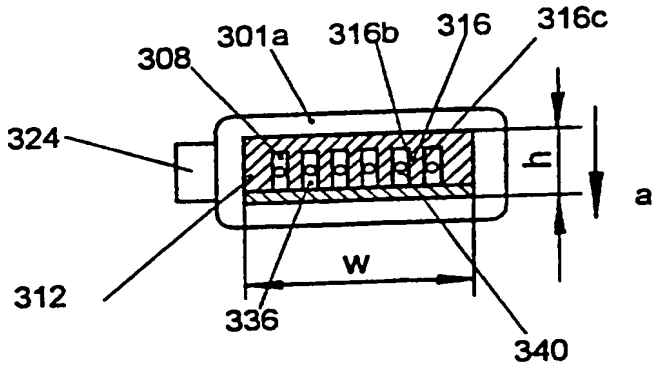
356
355b

Fig. 9A.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316c
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324
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a
W
312
336
340

Fig. 9B.

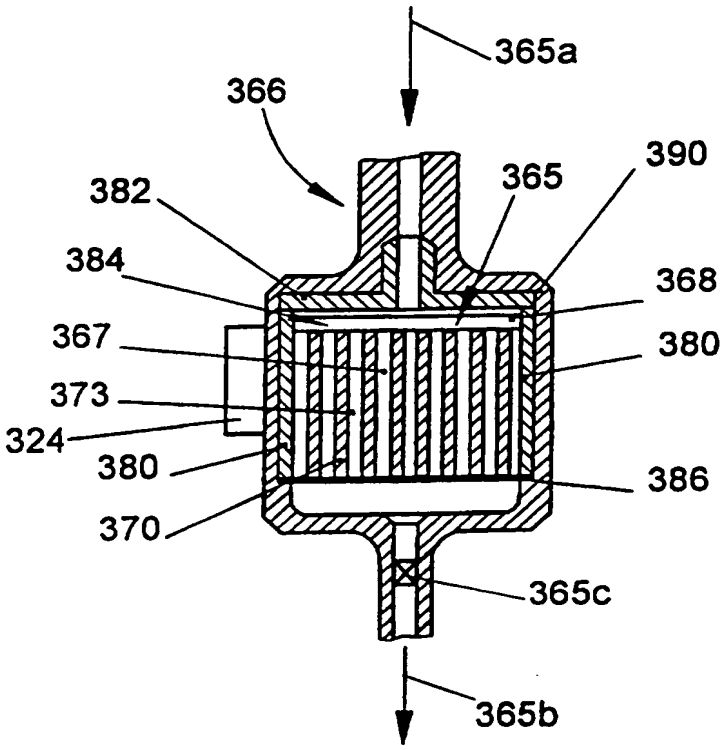

Fig. 10A.

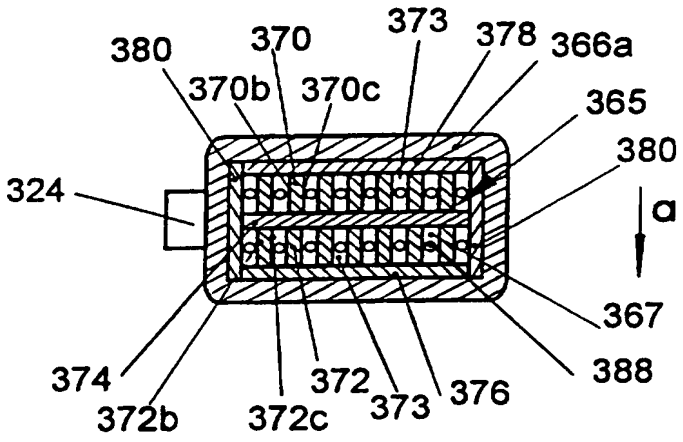

Fig. 10B.

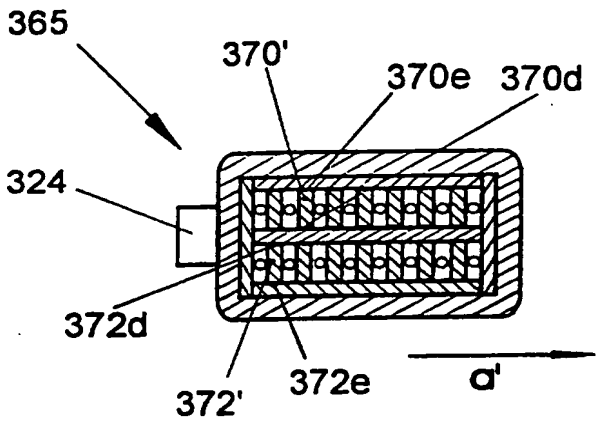

Fig. 10C.

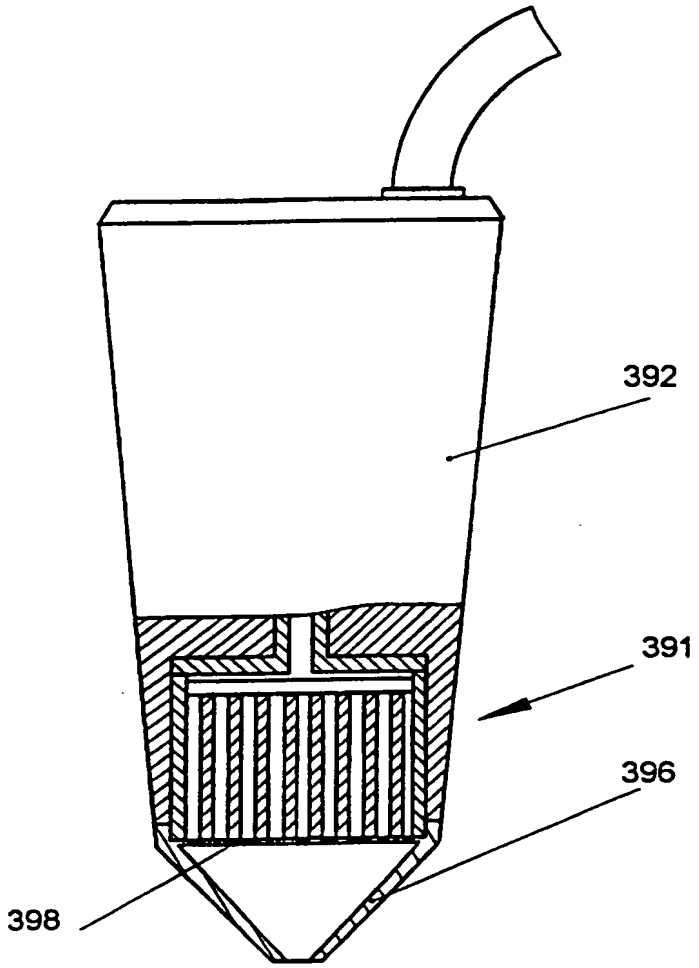

Fig. 11.

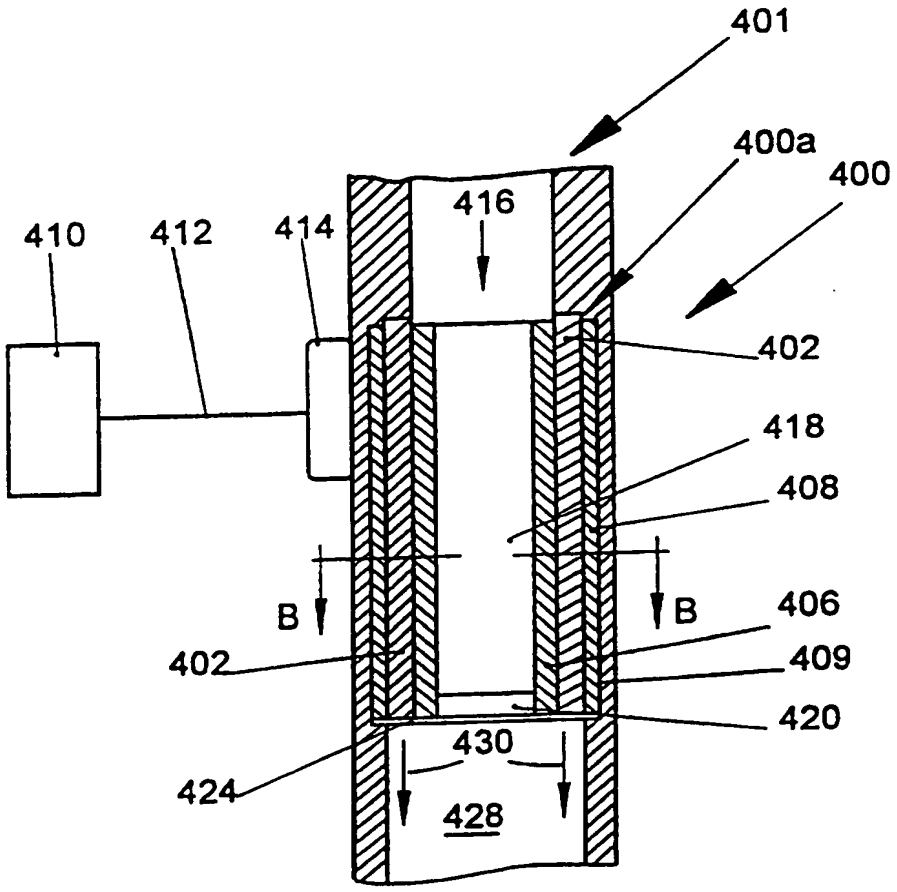

Fig. 12A.

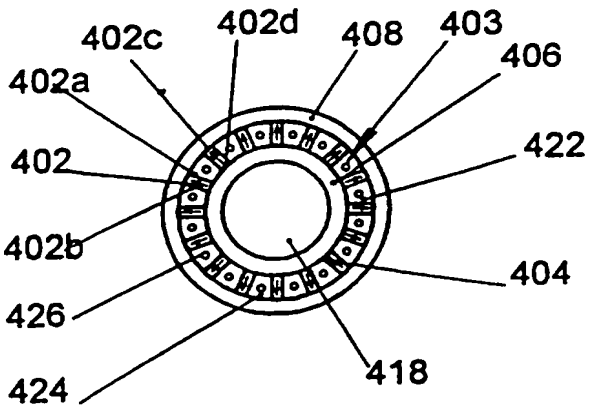

Fig. 12B.

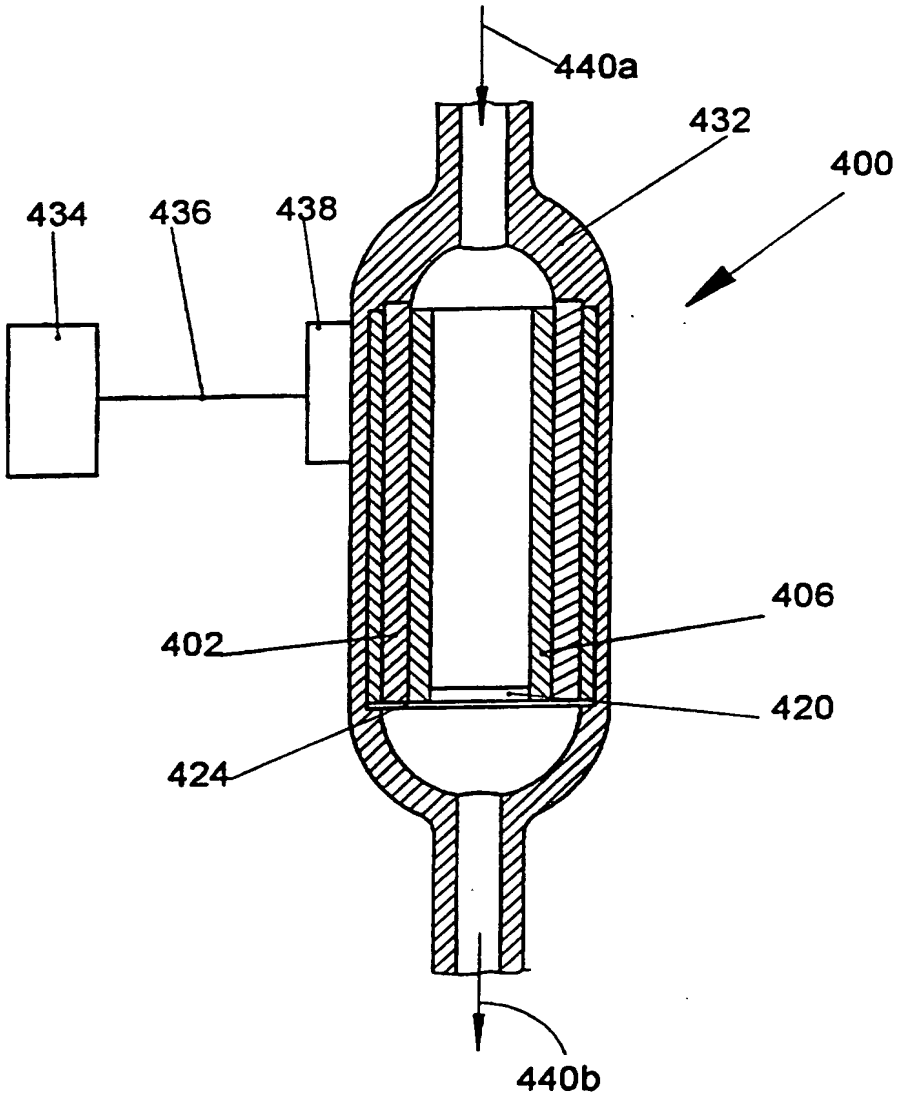

Fig. 13.

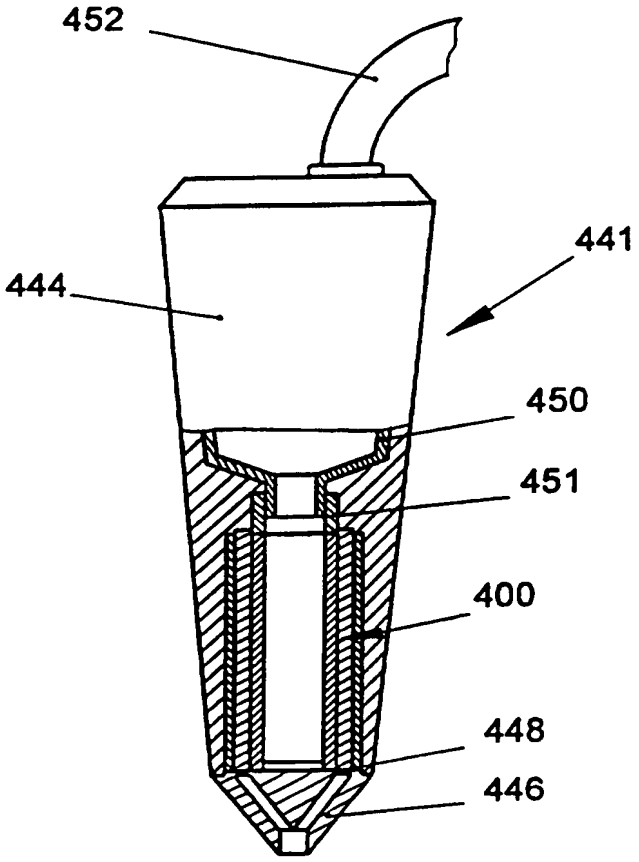

Fig. 14.

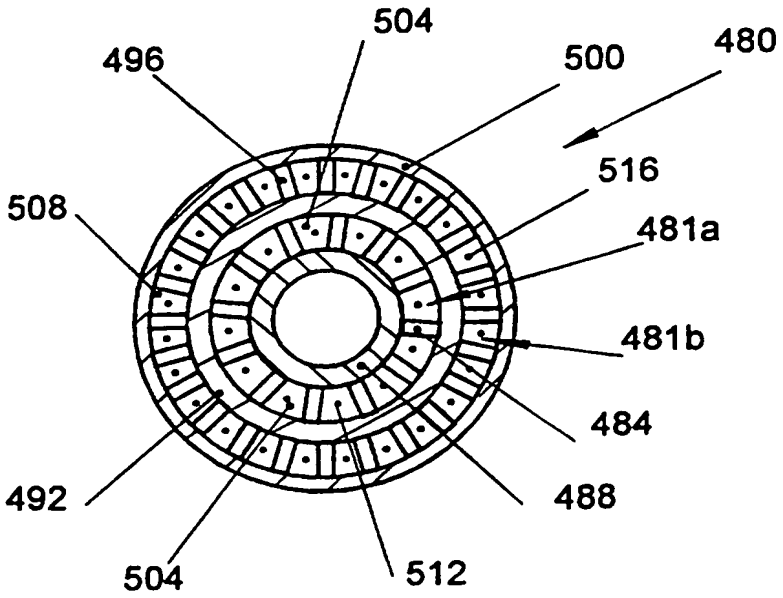

Fig. 15.

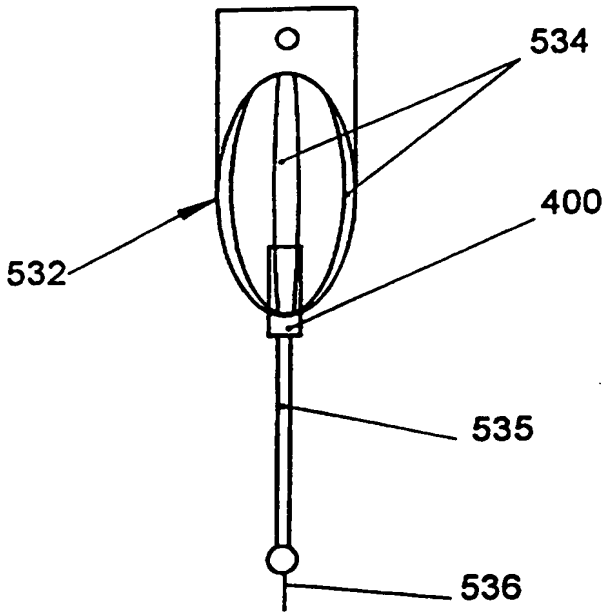

Fig. 16.

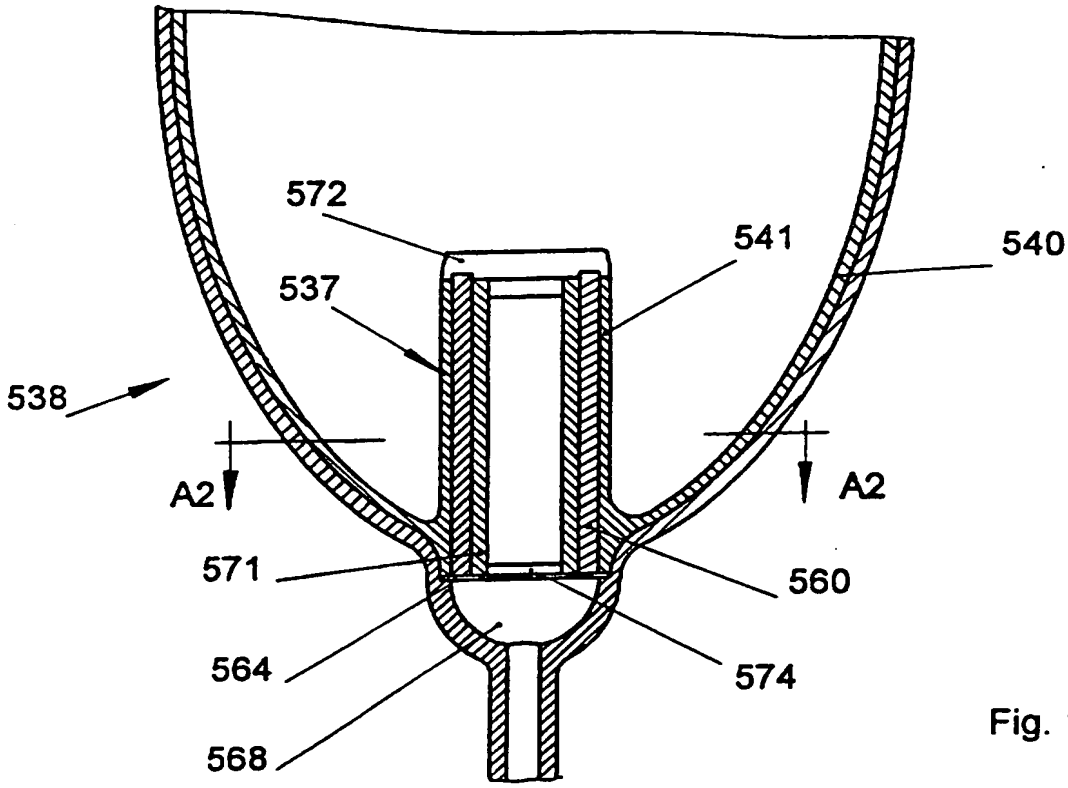

Fig. 17A.

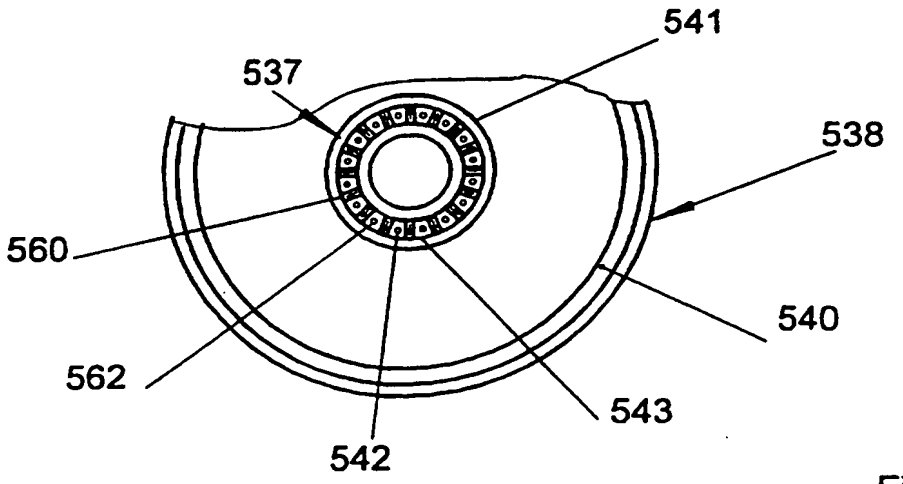

Fig. 17B.

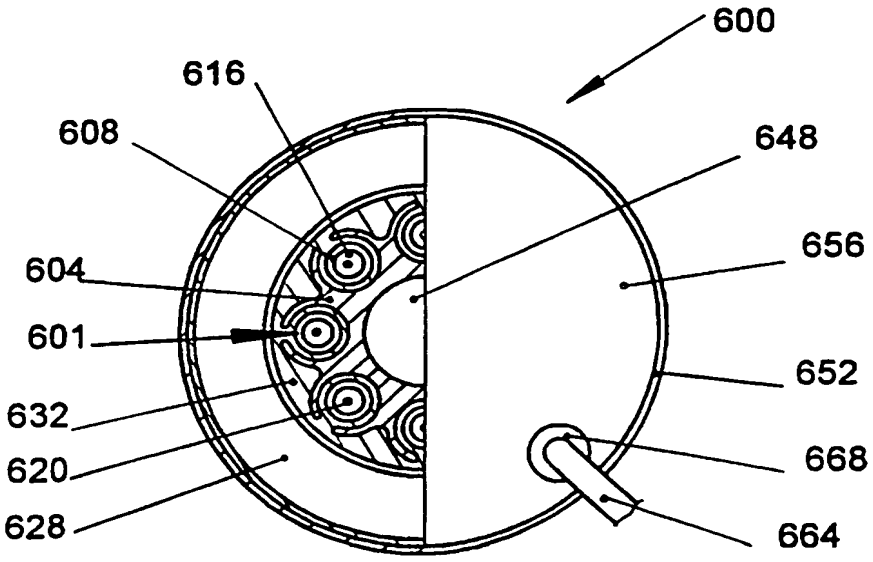

Fig. 18A .

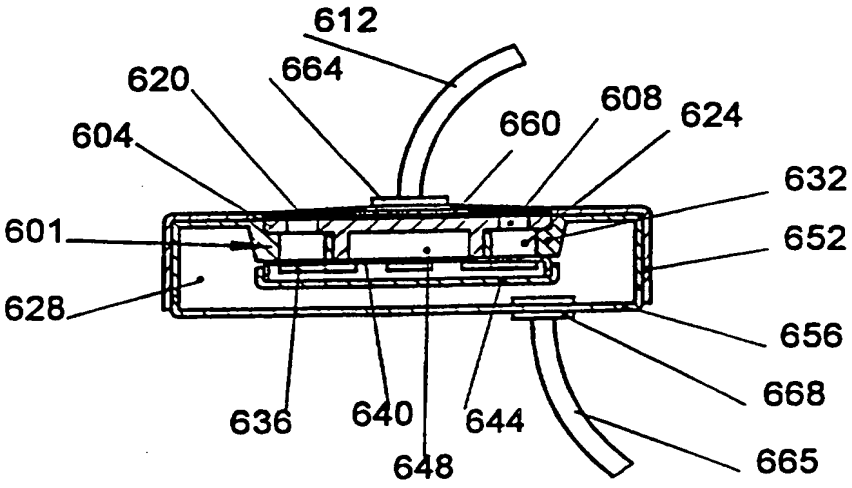

Fig. 18B .

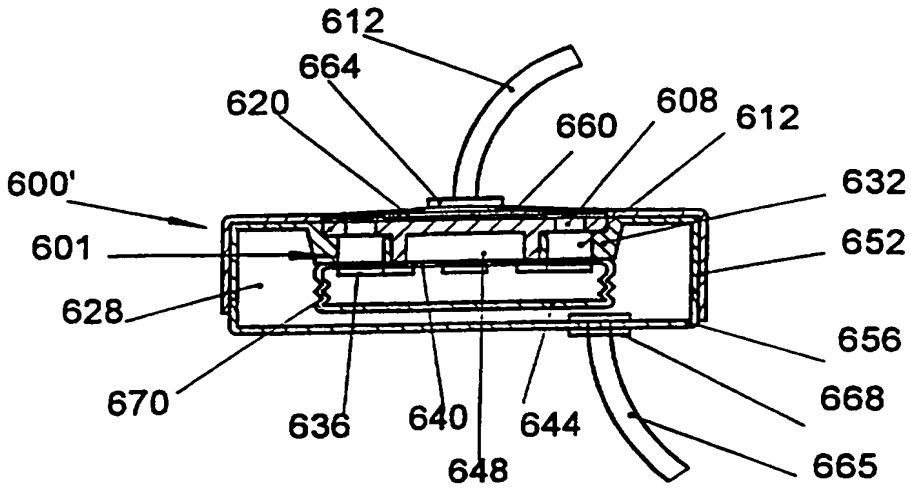
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Fig. 19.

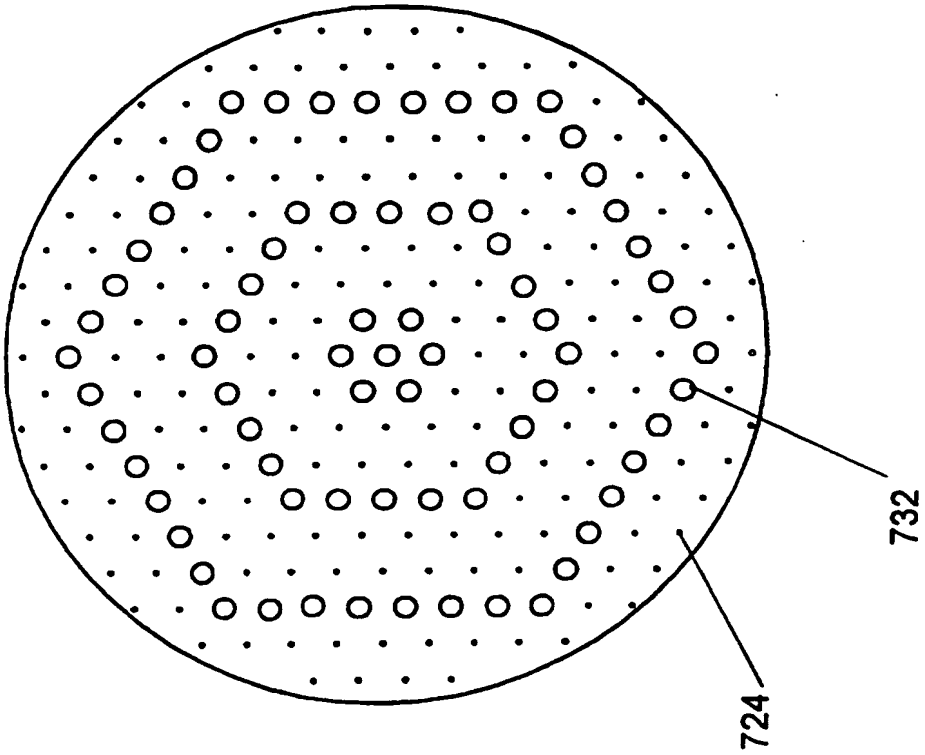

Fig. 20B.

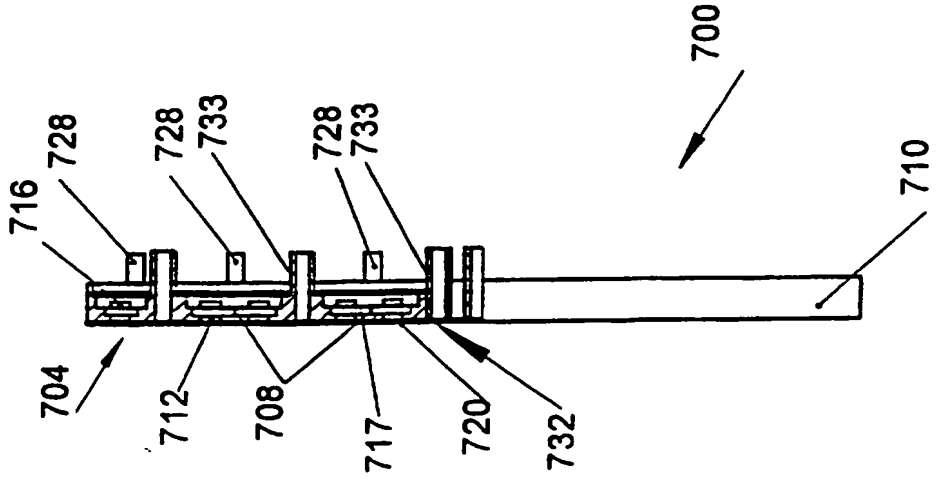

Fig. 20.A

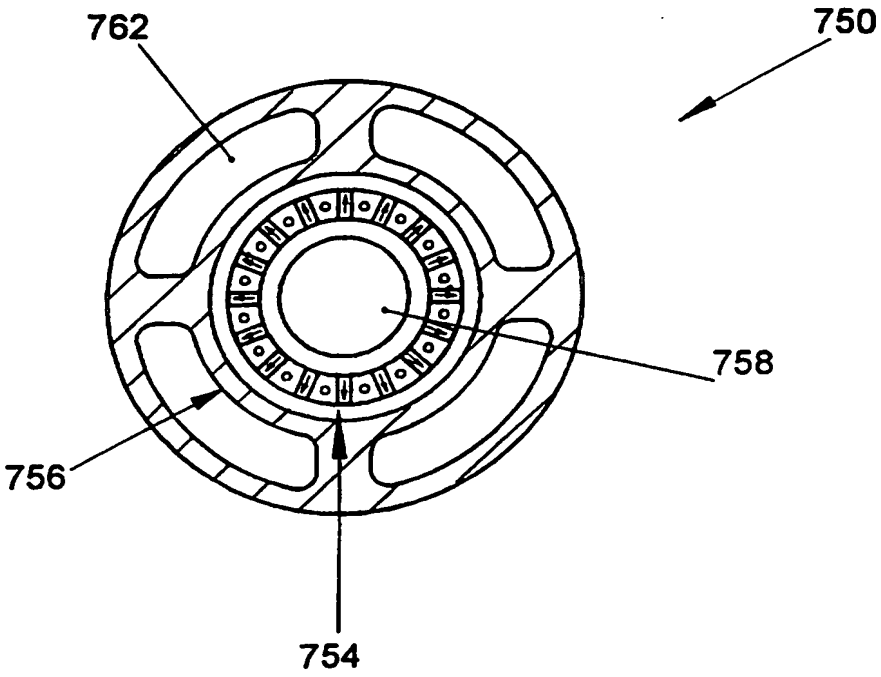

Fig. 21.

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(74) Agent: A. TALLY EITAN - ZEEV PEARL, D. LATZER & CO.; Law Offices, Lumir House, 22 Maskit Street, 46733 Herzlia (IL).

(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

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(88) Date of publication of the international search report:
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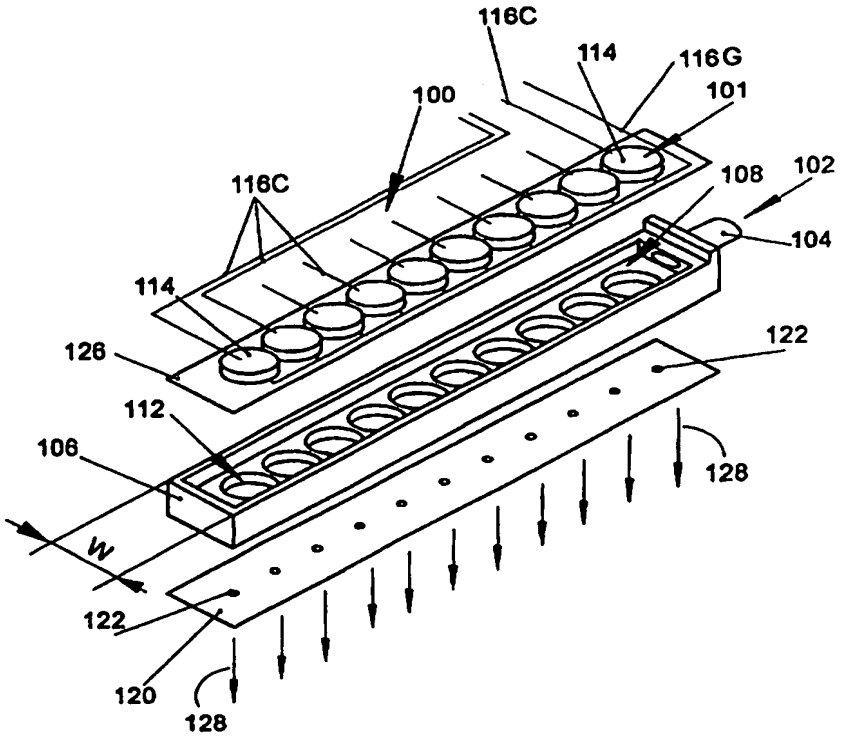
(54) Title: MULTICHANNEL MICRODOSING APPARATUS

(57) Abstract

A pumping apparatus has a body portion with a chamber and channels (112) for receiving fluid that has entered the chamber through an opening (104) in the body portion. The chamber is covered by a membrane and the channels terminate in orifices (122), through which fluid exits the pump. Electrosensitive members (114), movable in response to electric signals, are positioned on portions of the membrane corresponding to the respective channels, within the pump body and the respective orifices. A control mechanism controls pumping of this apparatus by sending electrical signals to the electrosensitive members, that force fluid through the respective channels and out the respective orifice for delivery to the desired site. The control mechanism permits movement of at least one of the electrosensitive members independent of the other electrosensitive members, as well as concurrent and simultaneous movement of the electrosensitive members, depending upon the pumping mode desired.



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UZ	Uzbekistan
VN	Viet Nam

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL96/00197

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : F04B 17/00
US CL : 417/413.2; 137/512, 533.11; 604/151

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 417/53, 322, 413.2, 478, 521, 540; 137/512, 533.11, 550, 454.4; 604/151, 152, 153

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	JP, 2-140475 A (MURANAKA et al) 30 May 1990, note Figs. 1, 4, 5 and 6.	1-5, 11, 12 and 24 --- 13-20
X -- Y	US 4,558,995 A (FURUKAWA et al) 17 December 1985, entire document.	11, 12, and 24 --- 13-20
X	US 5,192,197 A (CULP) 09 March 1993, entire document.	32, 33 and 37
Y, P	US 5,611,676 A (OOUMI et al) 18 March 1997, Fig. 2.	13-20
Y	US 3,325,155 A (BAHOUT) 13 June 1967, Figs. 7-12.	17-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
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Date of the actual completion of the international search
14 AUGUST 1997

Date of mailing of the international search report
11 SEP 1997

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Telephone No. (703) 308-0639

Form PCT/ISA/210 (second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL96/00197

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL96/00197

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING
This ISA found multiple inventions as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claim(s) 1-37, 44-47, AND 50-63, drawn to a microdosing pump having electrosensitive members which act against a membrane.
Group II, claim(s) 32-43, 48 and 49, drawn to a microdosing pump having elctrosensitive members which are rods.

The inventions listed as Groups I and II do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: Group I is directed to a pump apparatus having a channel which communicates with a chamber partially defined by a membrane that has plural electrosensitive members acting upon it to cause a pumping action. Group II is directed to a pump having plural channels which are formed between electrosensitve rod members.
The common technical featrues amoung the groups of claims are that the pumps have a channel, electrosensitive members and means for controlling the electrosensitive members. Each of Furukawa et al (U.S. Patent Number 4,558,995) and Culp et al (U.S. Patent Number 5,267,841) disclose pumps with a channel, electrosensitive members and control means for the electrosensitive members. Furukawa et al is a devise similar to Group I, the applicants attention is drawn to Figs. 3 and 5 which discloses the common elements between the groups. Culp et al is a devise similar to Group II, the applicants attention is drawn to Fig. 3 which discloses the common elements betwen the groups. Accordingly, there are no common "special", i.e. patentable, features recited in these two groups of claimed inventions. It is noted that Group II does not disclose the electrosensitive members acting against a membrane and Group I does not disclose the channels being formed by electrosensitive rod members.